Storage Ring Kicker Update

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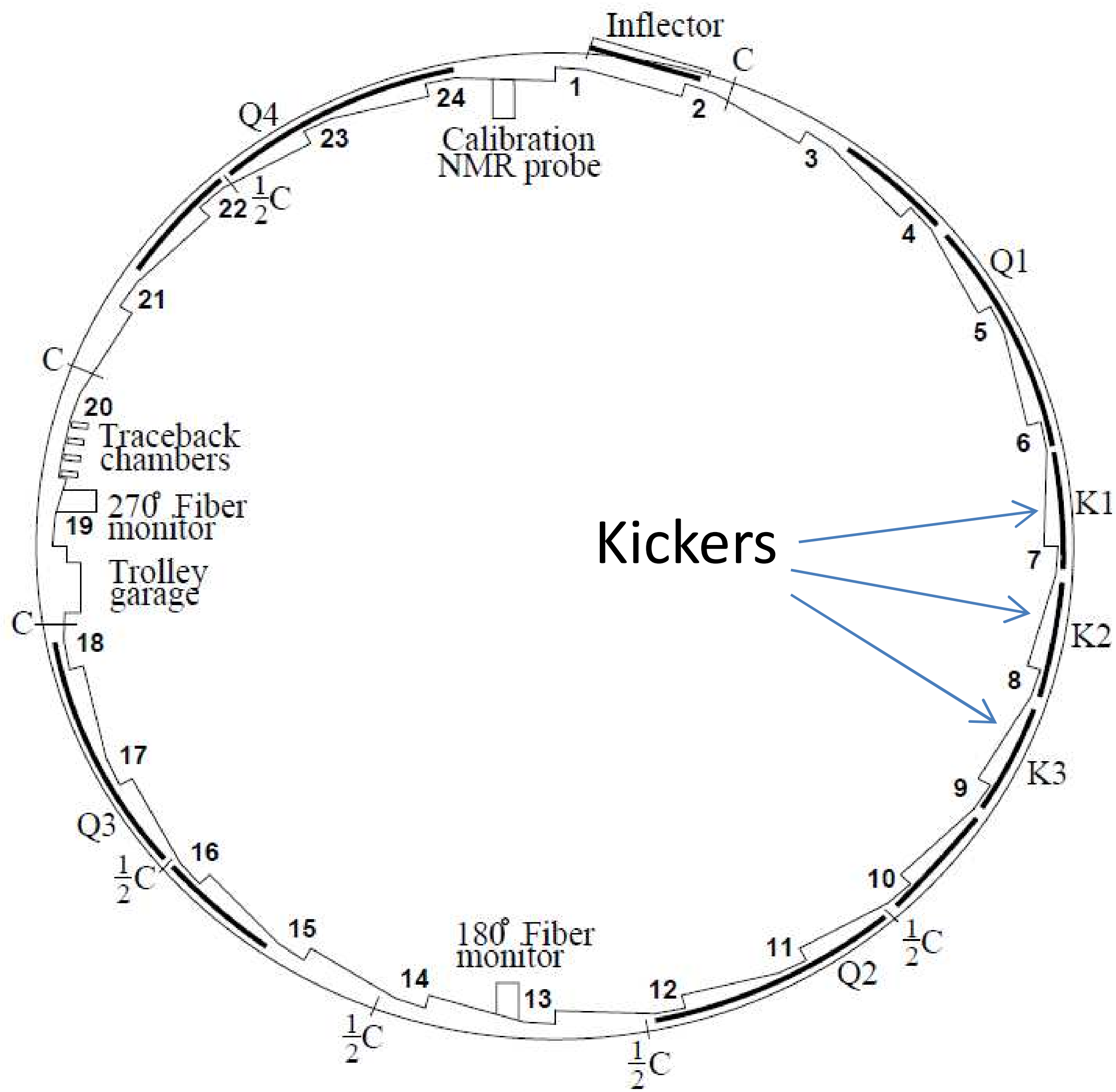
Cornell University
June 28, 2012

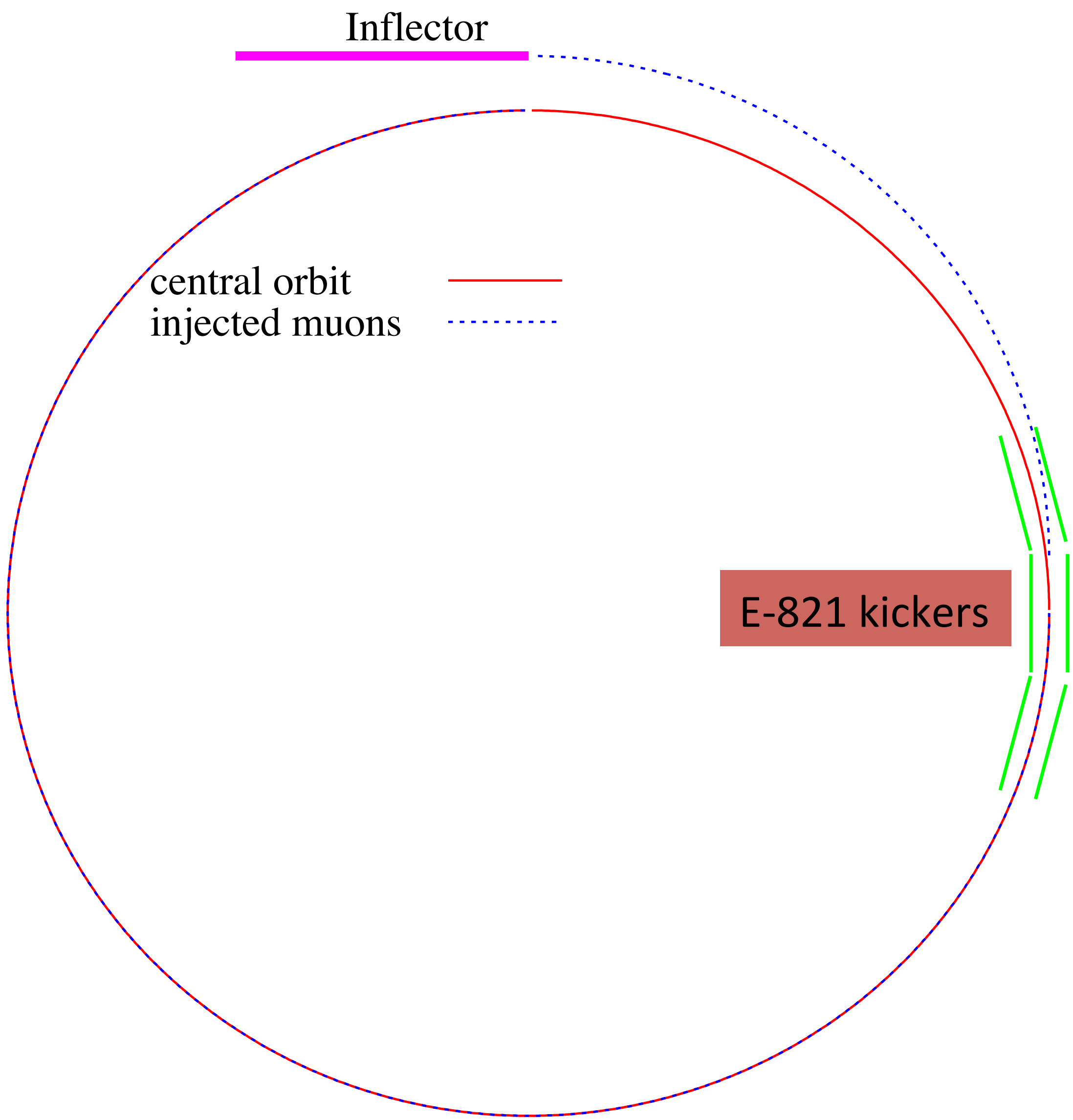
- Kicker function
- Kicker magnet
- Pulser
- Pulser test status



Kickers are 90° in betatron phase from the inflector exit

Injected muons are crossing the central trajectory inside the kickers

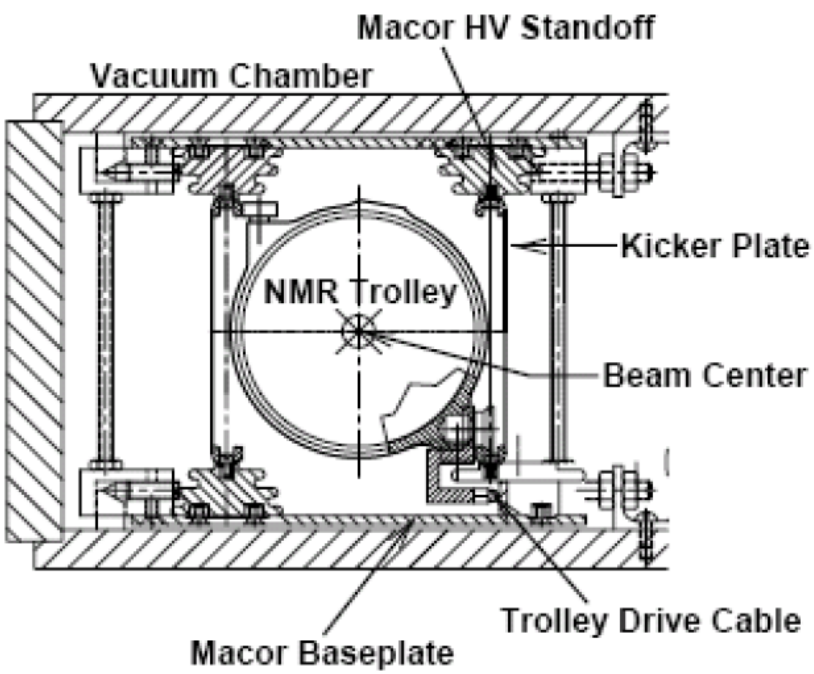
Kick directs muons onto central orbit

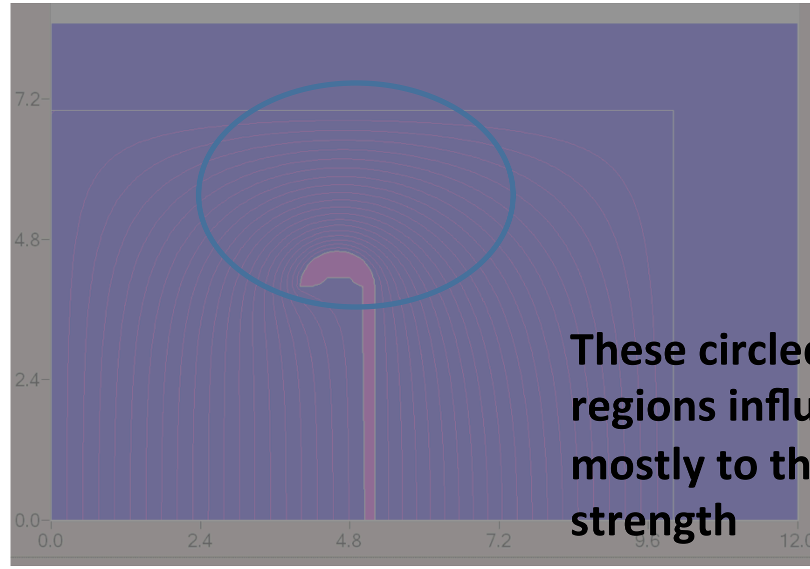


End of inflector is displaced 7.7cm radially outward from the central orbit

Radius of central orbit = 7.112 m

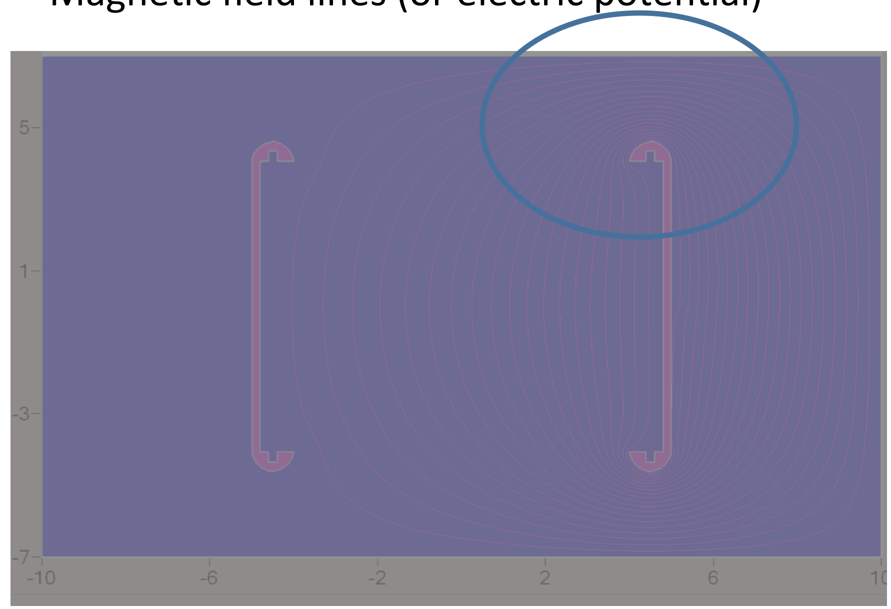
Kick ~ 10 mrad on first pass and
0 on next turn





These circled regions influence mostly to the field strength

Magnetic field lines (or electric potential)

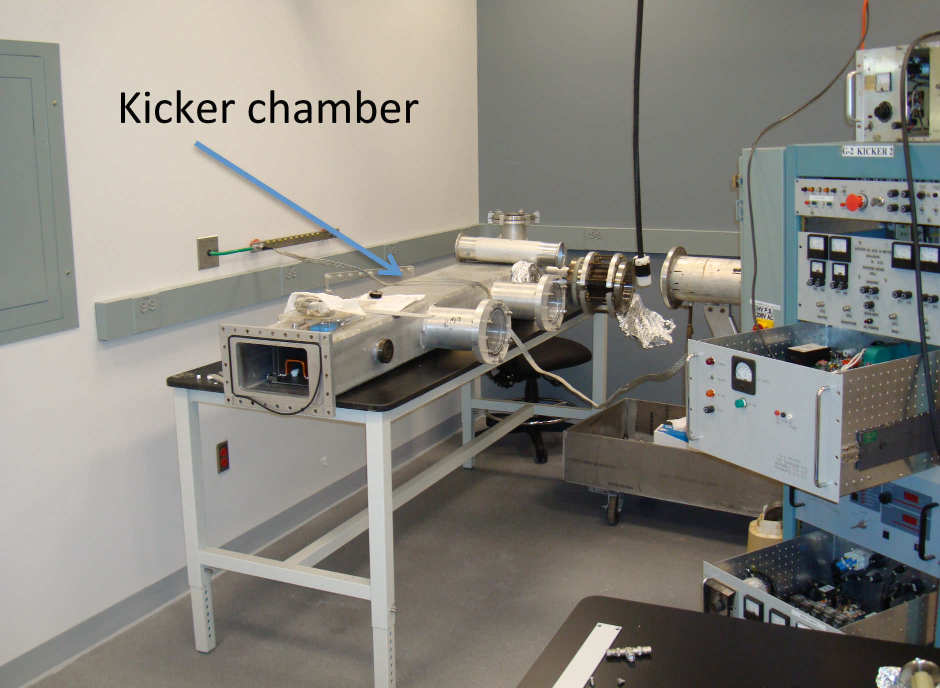


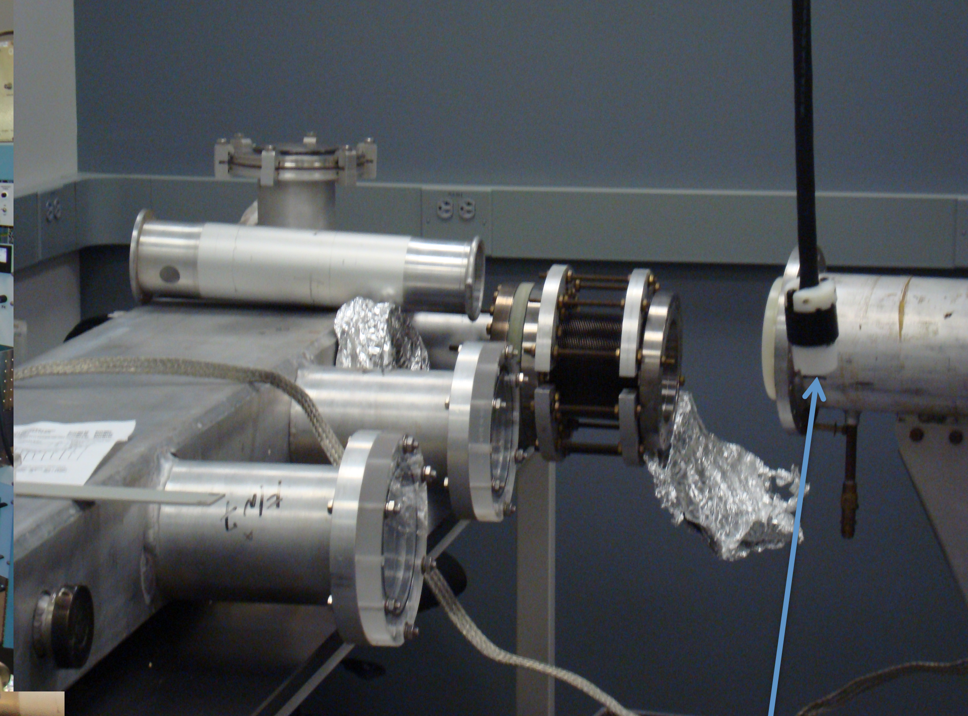
Field distribution in transient moments

Kicker has 3 identical sections of 1.76 m-long each

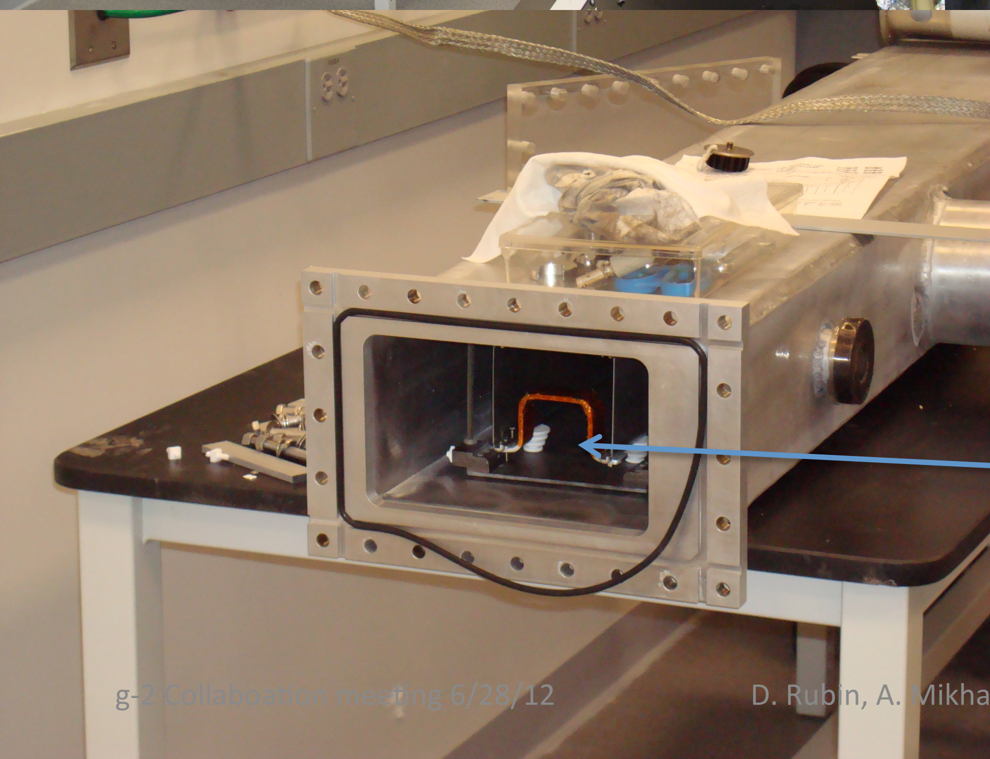
Each section fed by individual HV pulser

Kicker chamber



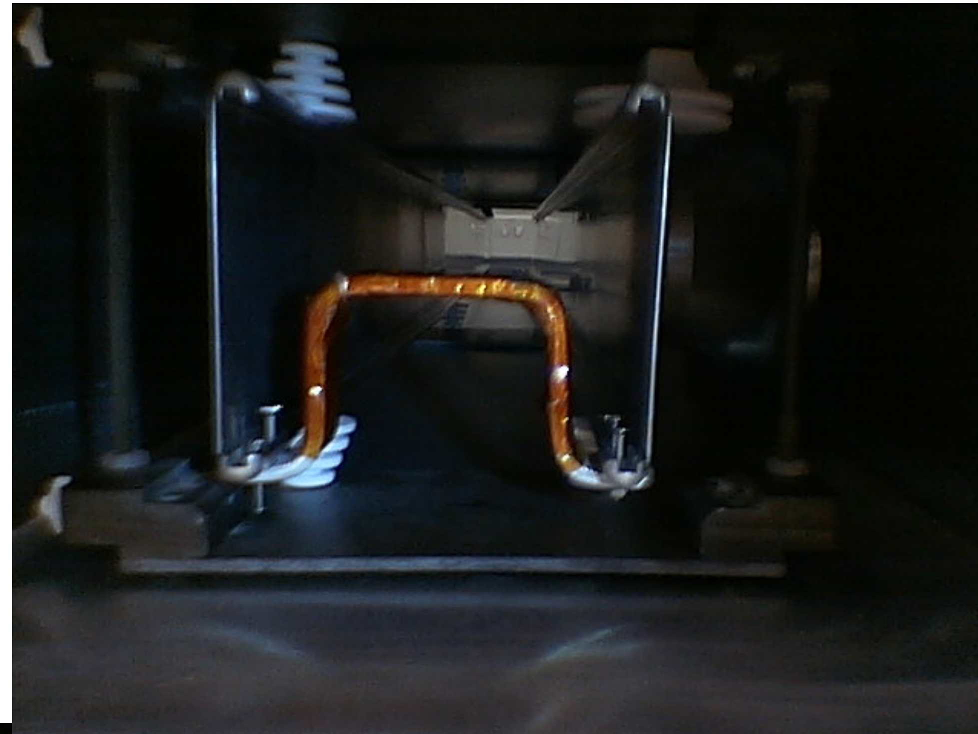


Power



Downstream end of kicker

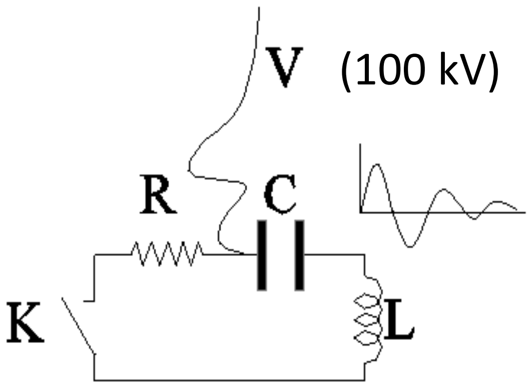
E-821 prototype kicker plates

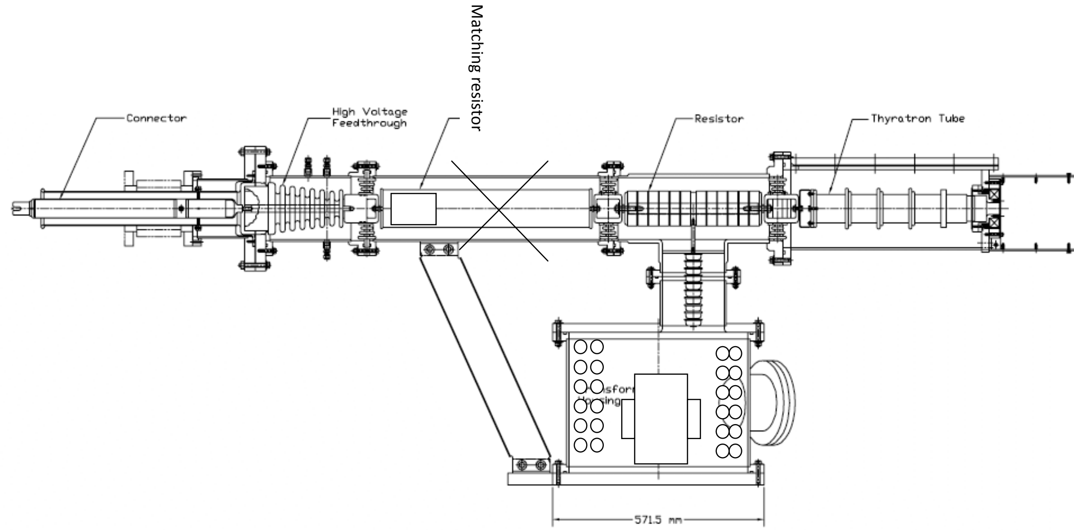


End jumpers in the model

Macor© insulators

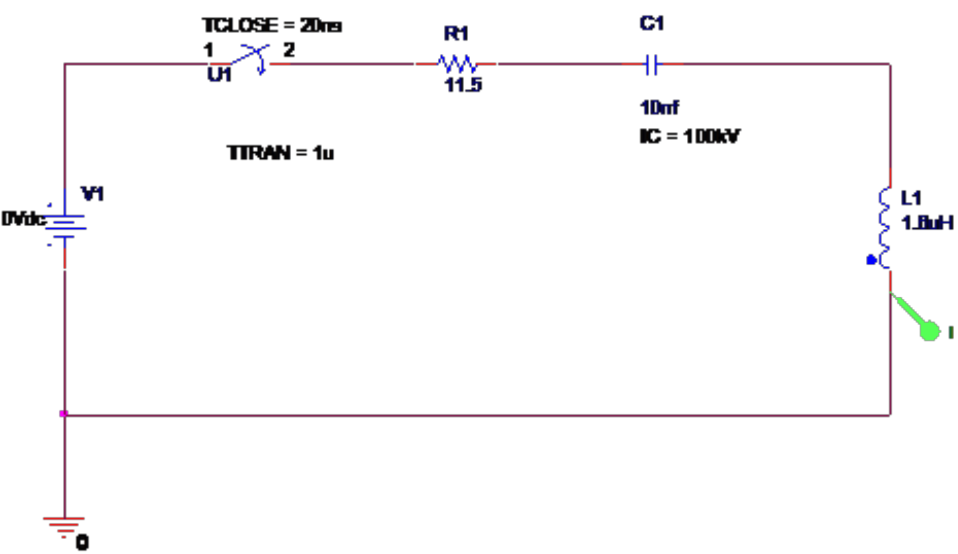
Modeling E-821 pulser with SPICE

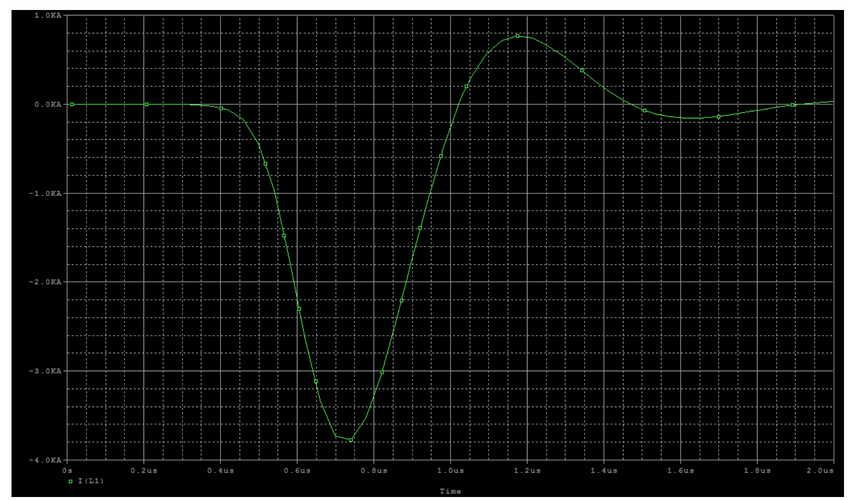


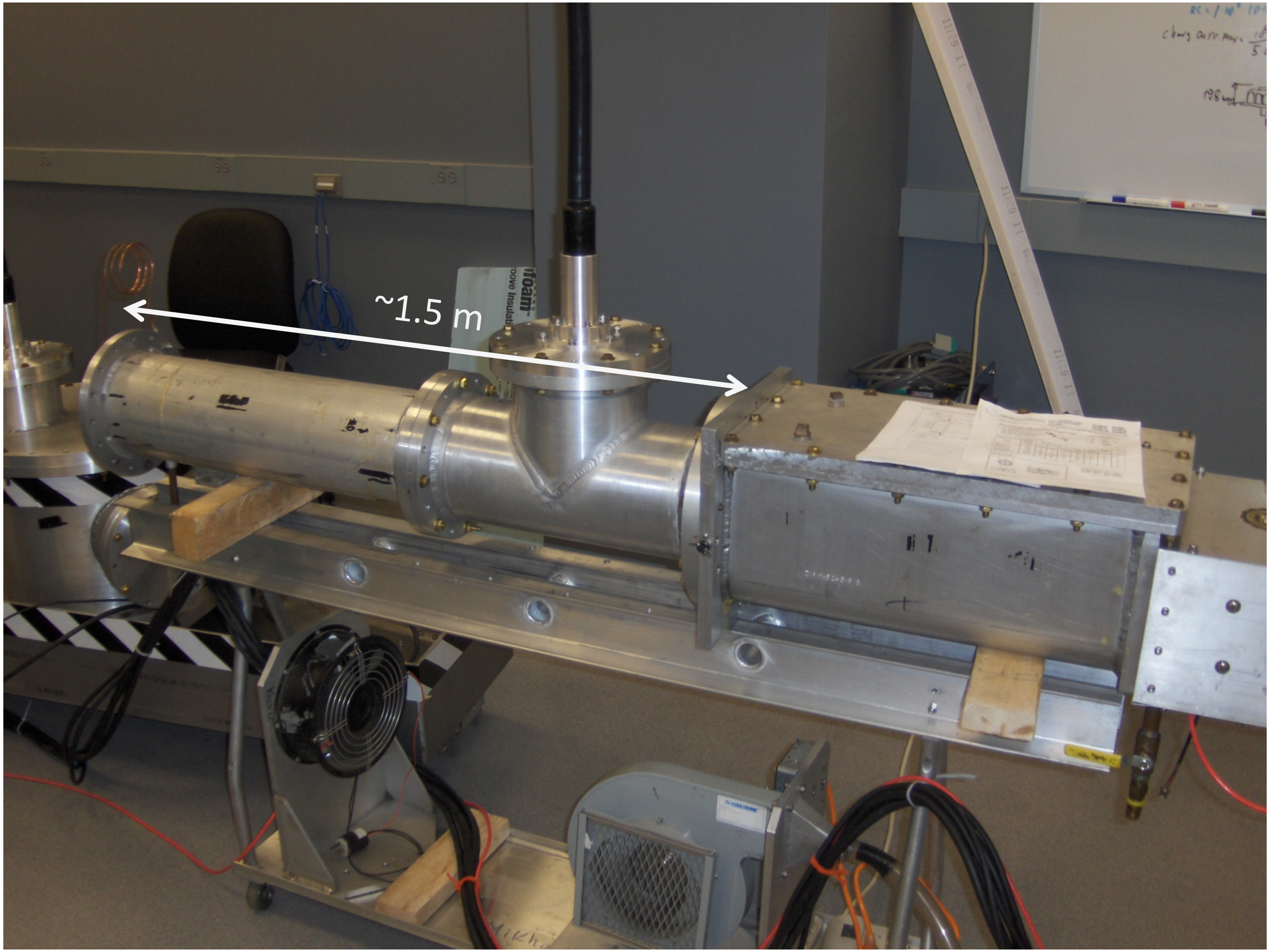


t

E-821 pulse (200ns/big division)






~1.5 m

Kicker Magnet

Kicker changes angle by $\theta = x_{inf}/\beta \cong 10$ mrad to put injected muons on central orbit

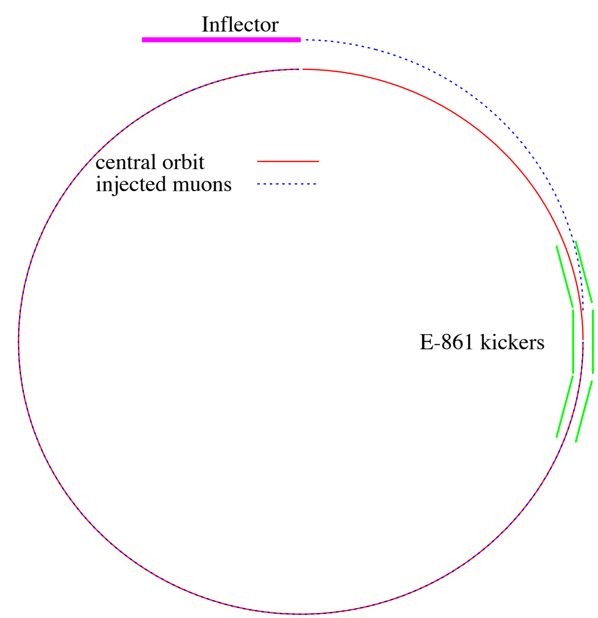
Now suppose the injected muon has fractional energy error $\Delta E/E = \delta$

The ideal kick for off energy muons is $\theta = (x_{inf} - \eta\delta)/\beta = (x_{inf} - x)/\beta$

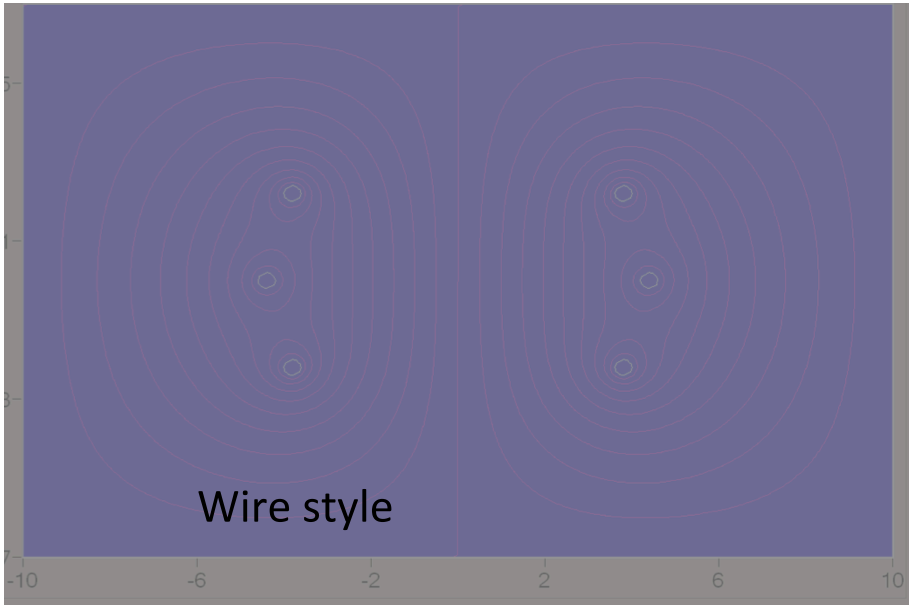
But the ideal kick for on energy muons with finite divergence angle ϕ emerging from inflector is $\theta = x_{inf}/\beta$, independent of ϕ

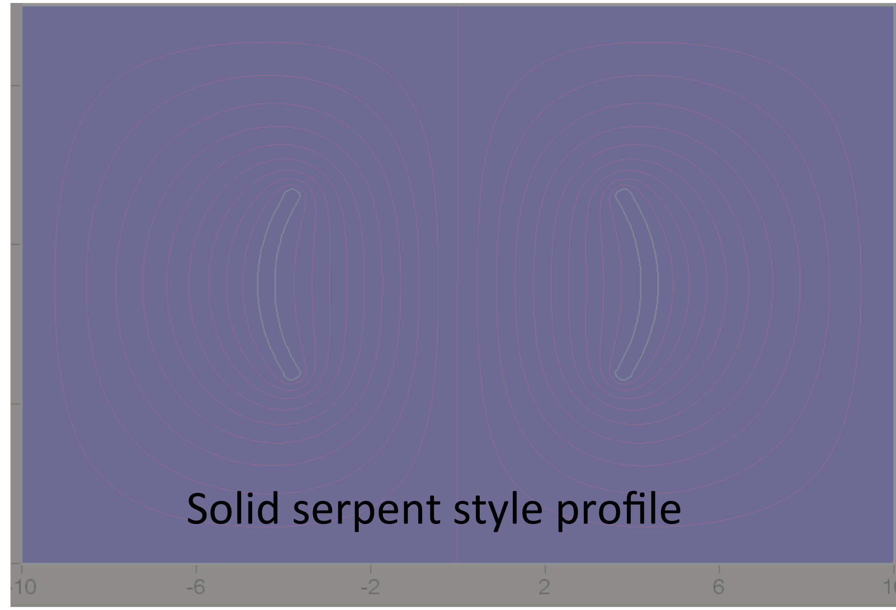
Optimum radial field profile depends on energy and angular distribution of injected beam

Proceed with design that gives uniform field



Some profiles of the kicker electrodes and guidelines





L.Roberts, "Kicker R&D Work Plan: Options and Time Estimates", New Muon (g-2) Technical Note #003, August 14, 2008.

Serpent profile yields 70% greater B-field/Amp than E-821 style

Make an impedance of the stripline kicker as low as possible;

Take care on the field distribution

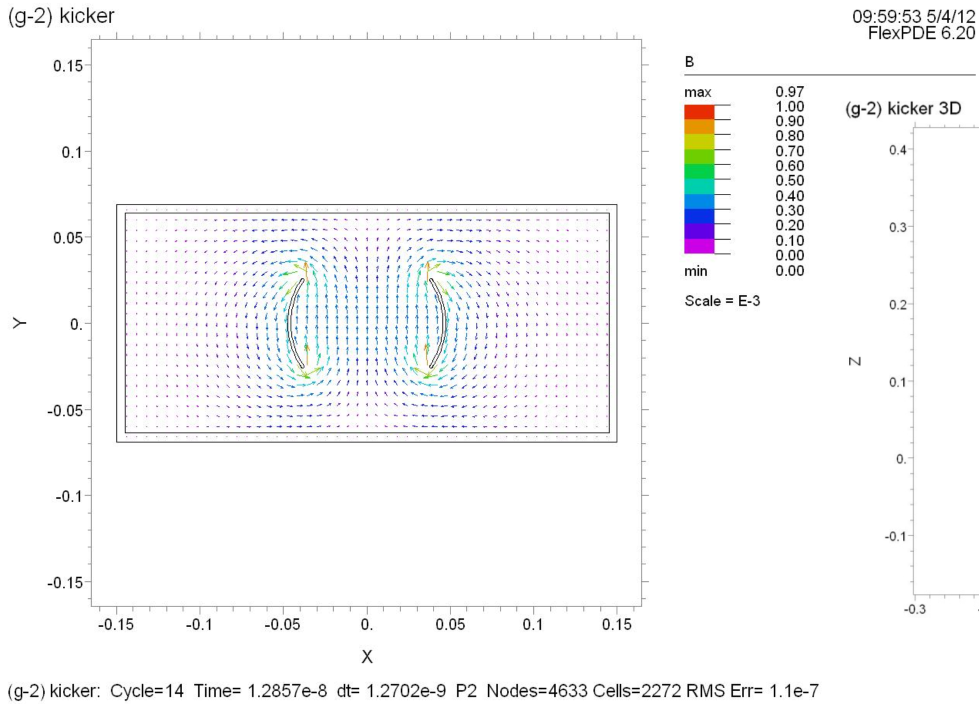
Choice of materials

Stray fields in surroundings are another subject for research.

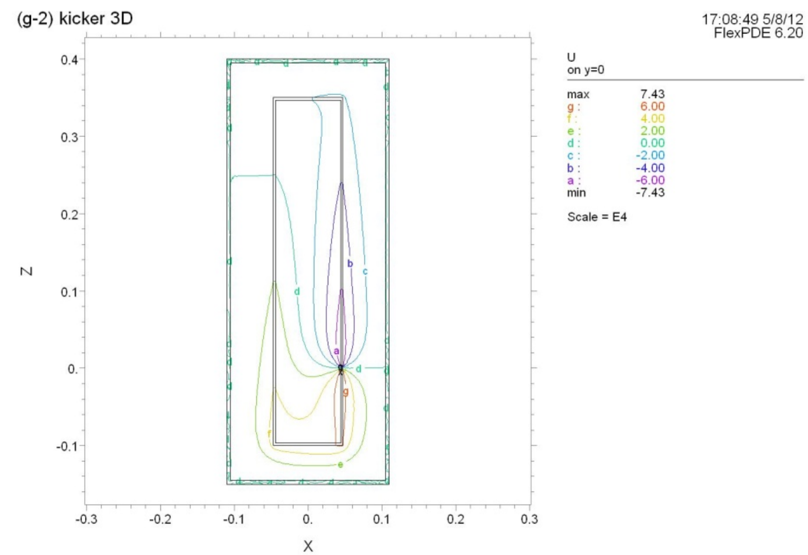
Profile of electrodes will be chosen with appropriate 3D modeling

3D field calculation is in progress with FlexPDE

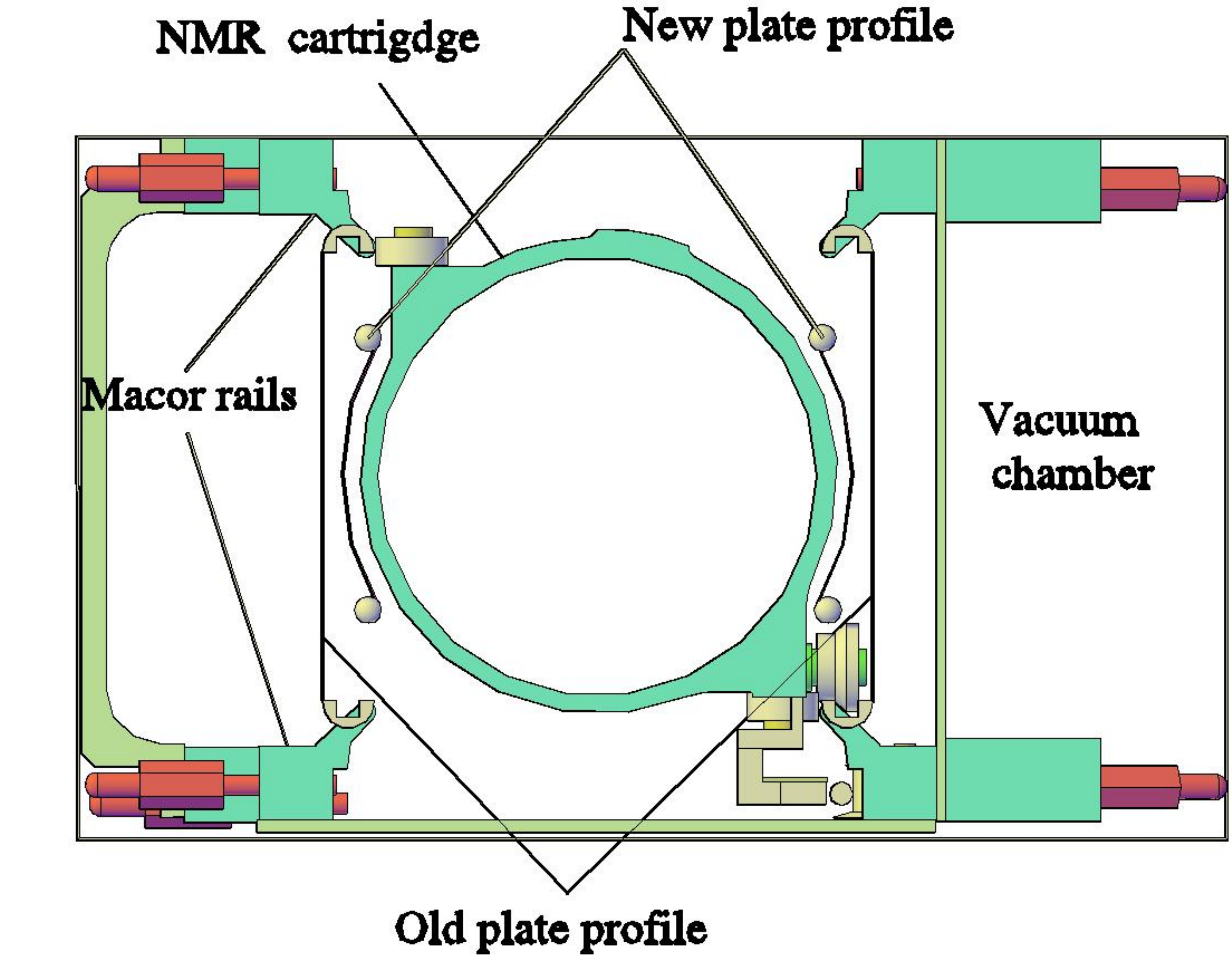
Plans to do this with HFSS and CTS studio (License granted)



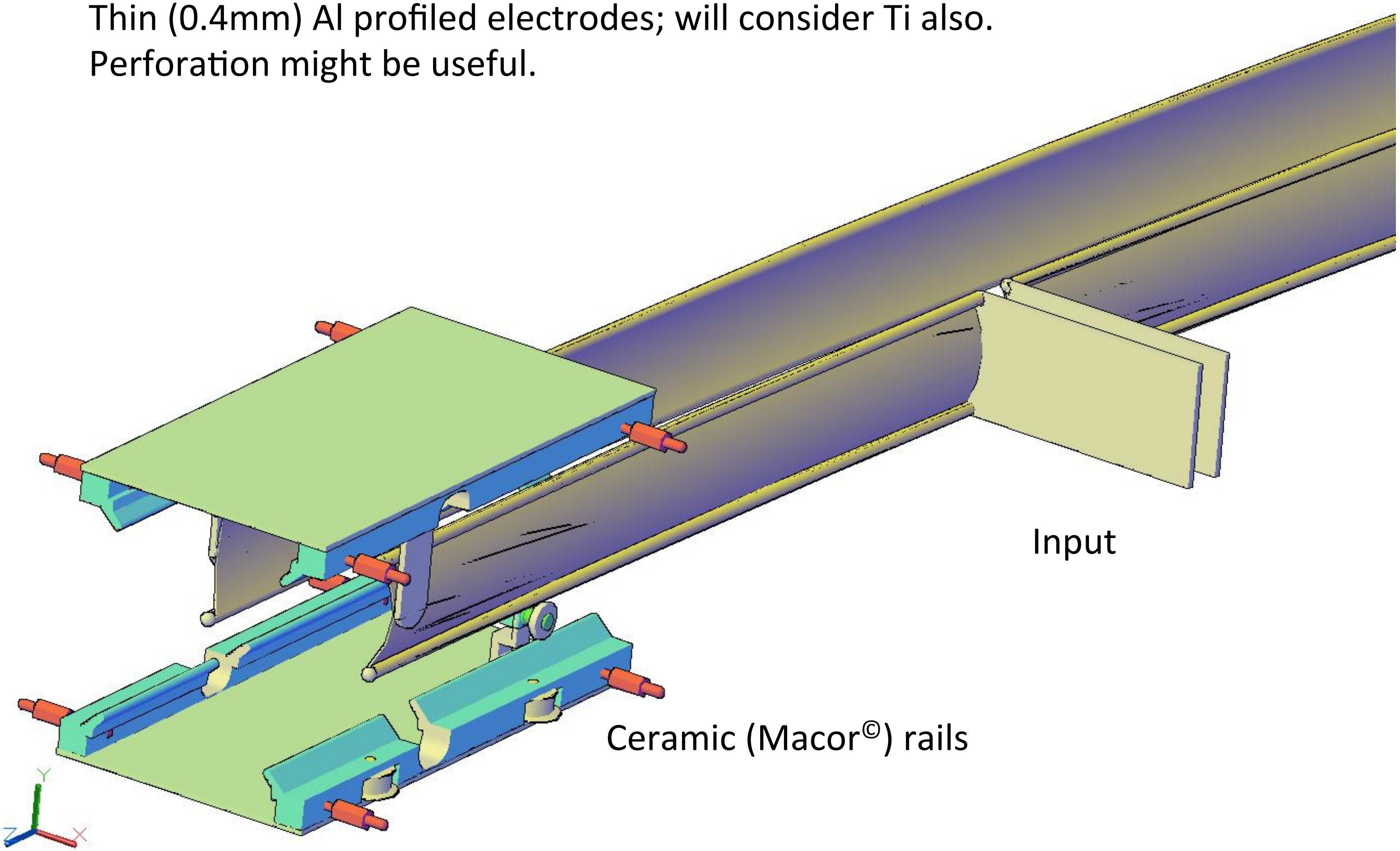
Field distribution in a transverse plane

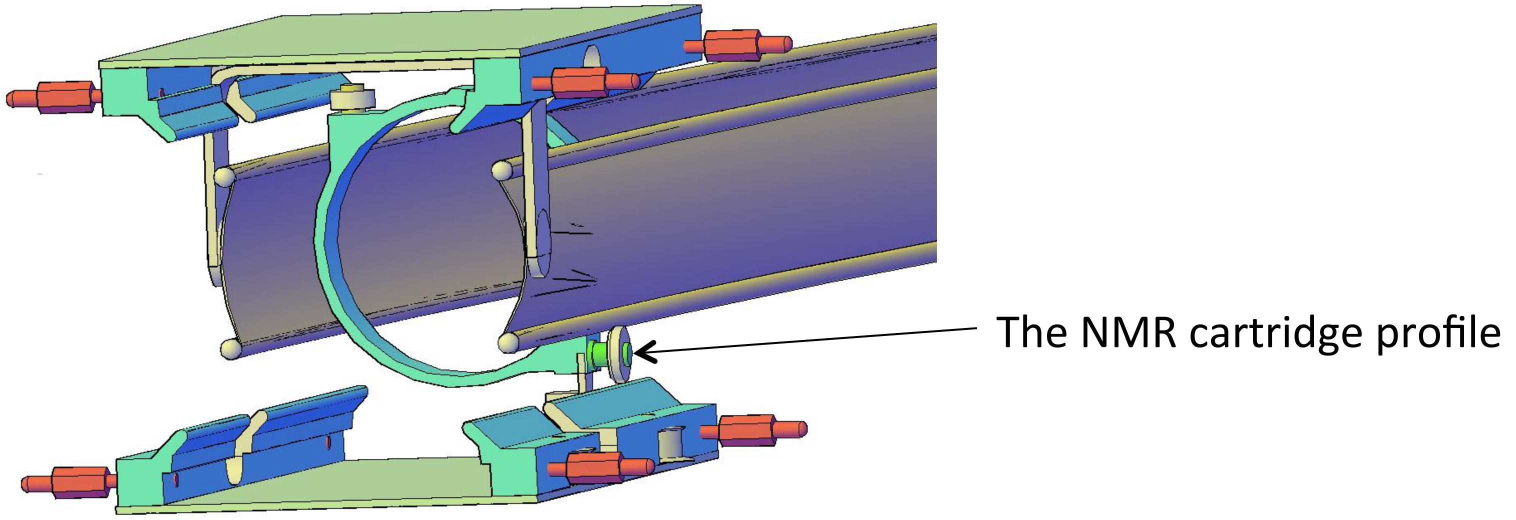


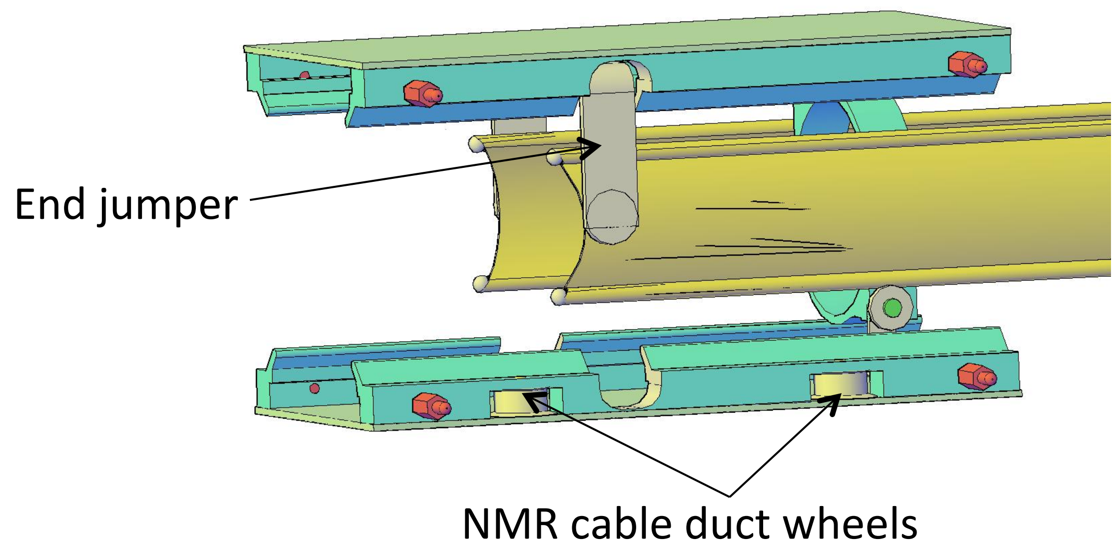
Potential distribution.
Longitudinal cut, top view

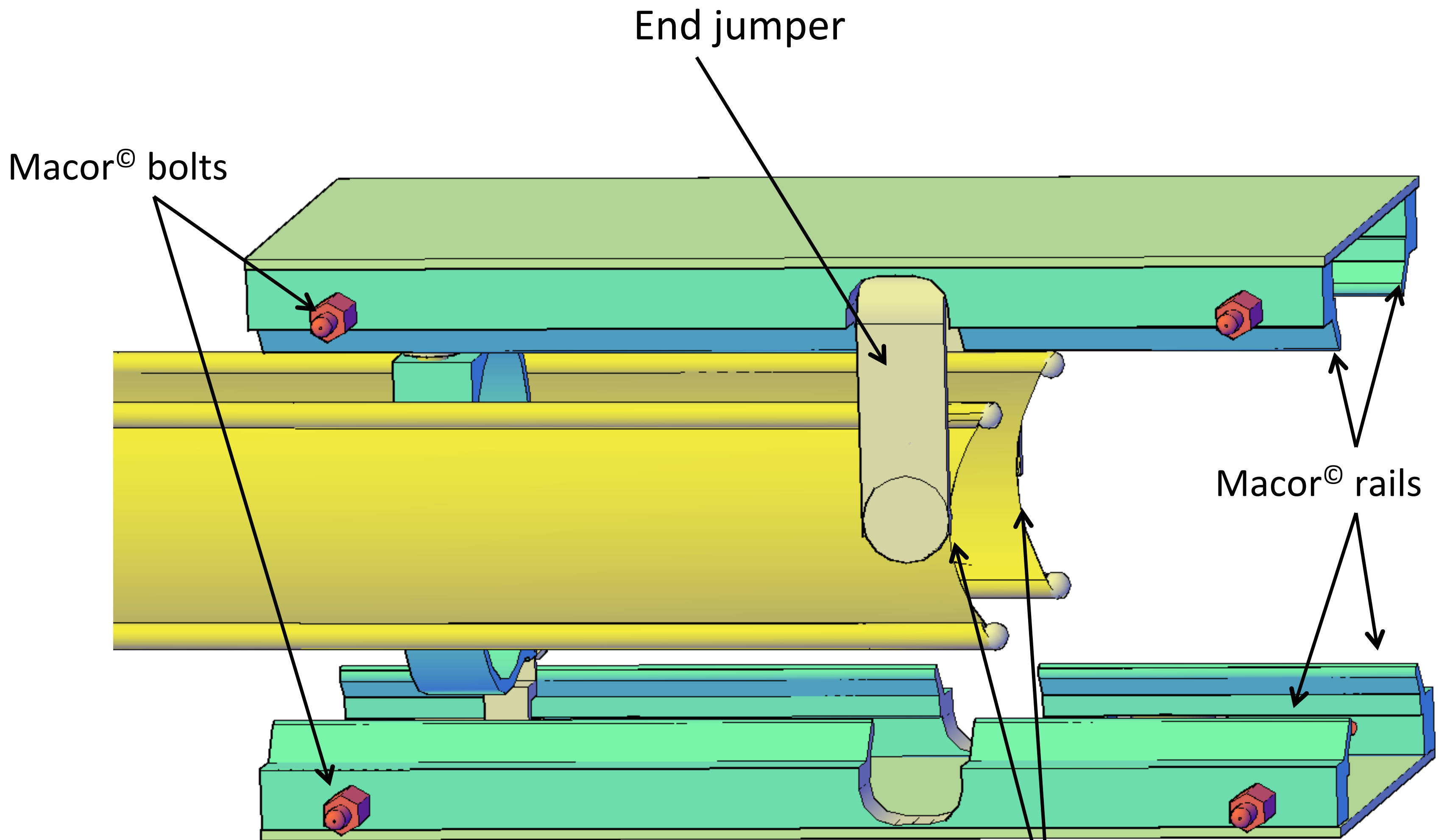

NMR cartrigdge
New plate profile
Macor rails
Vacuum chamber
Old plate profile

Thin (0.4mm) Al profiled electrodes; will consider Ti also.
Perforation might be useful.



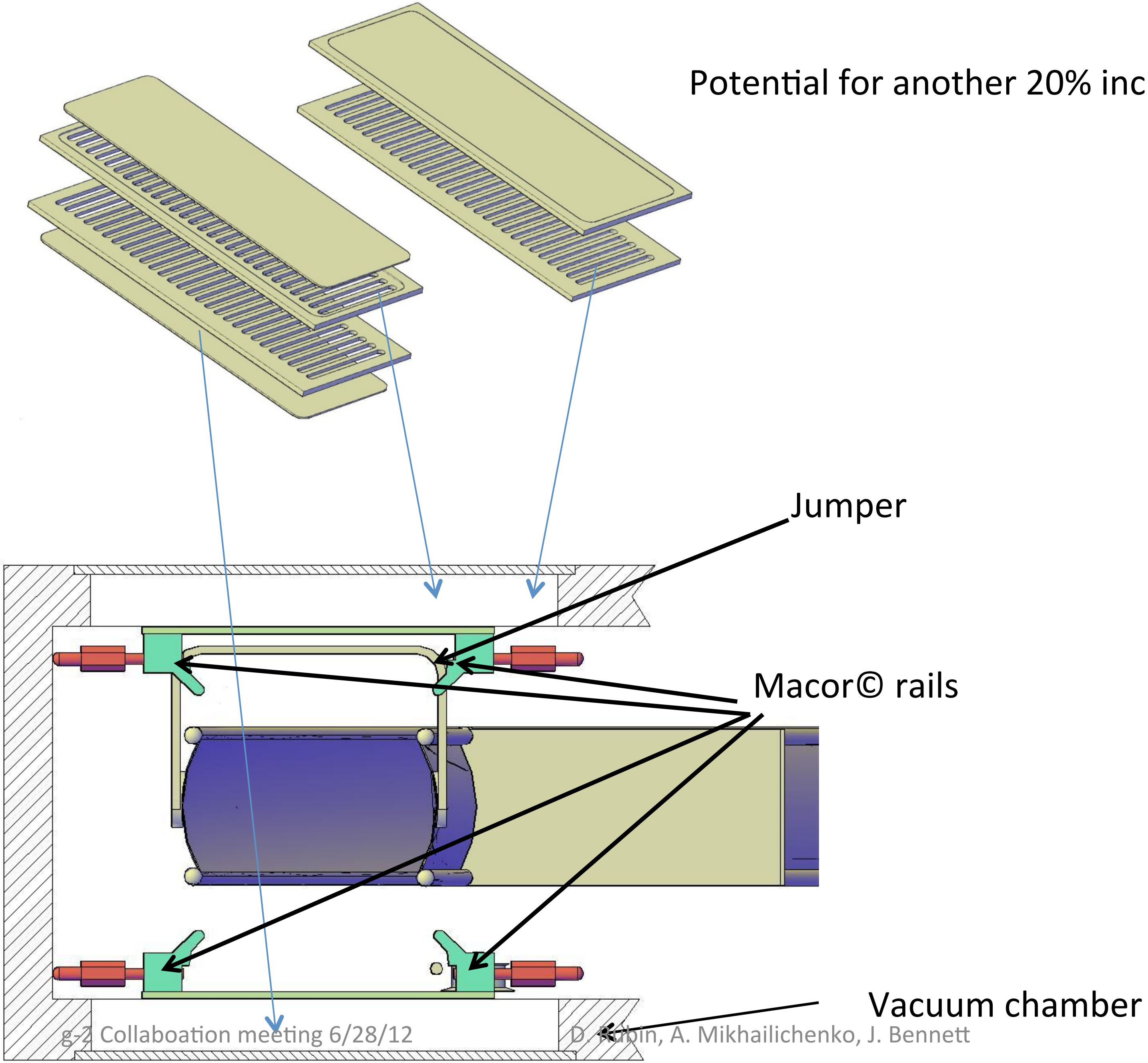

The NMR cartridge profile


End jumper
NMR cable duct wheels



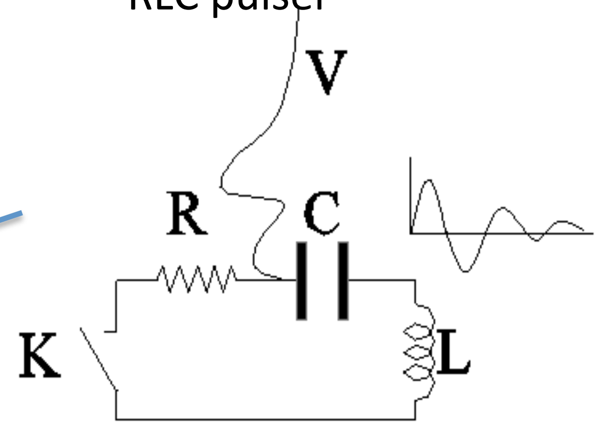
Electrodes at the end will have the chamfer (similar to the magnetic pole chamfer) for better 3D field distribution. (The same could be recommended for the electrostatic Quadrupole)

Potential for another 20% increase of kick

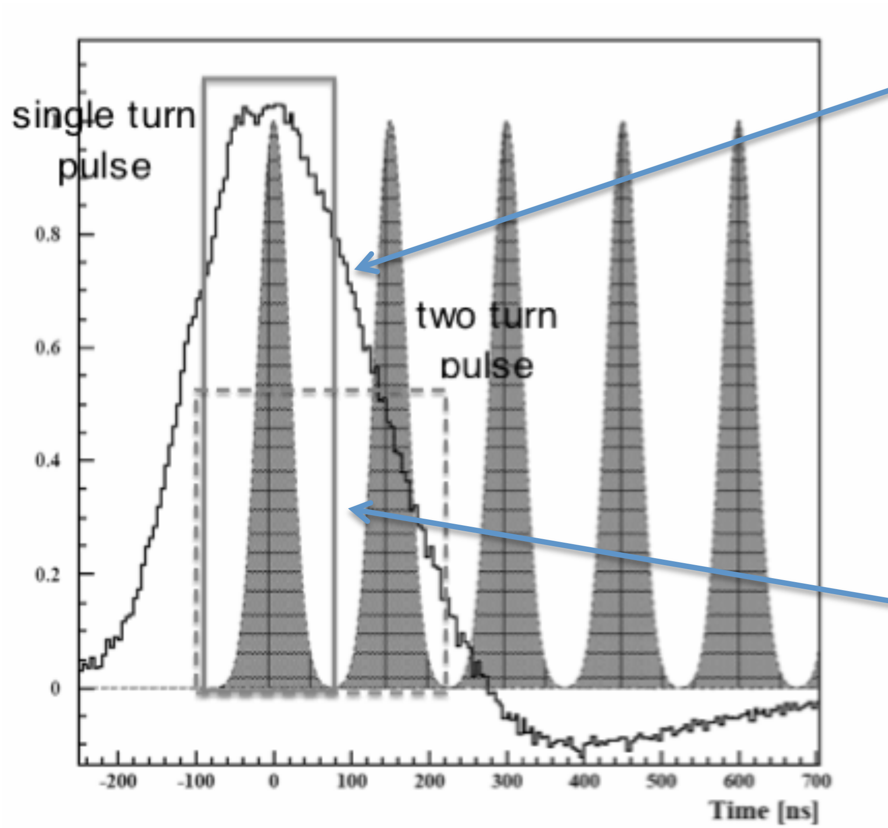


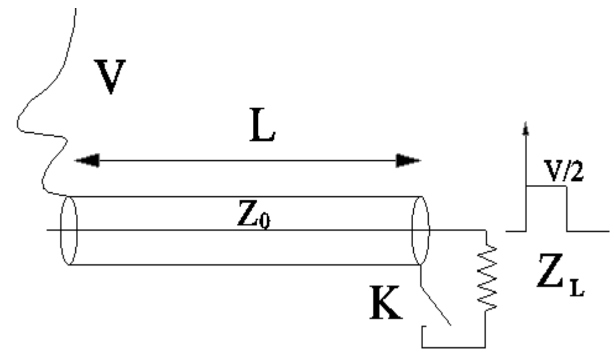
Pulser

RLC pulser



Kicker Pulse width

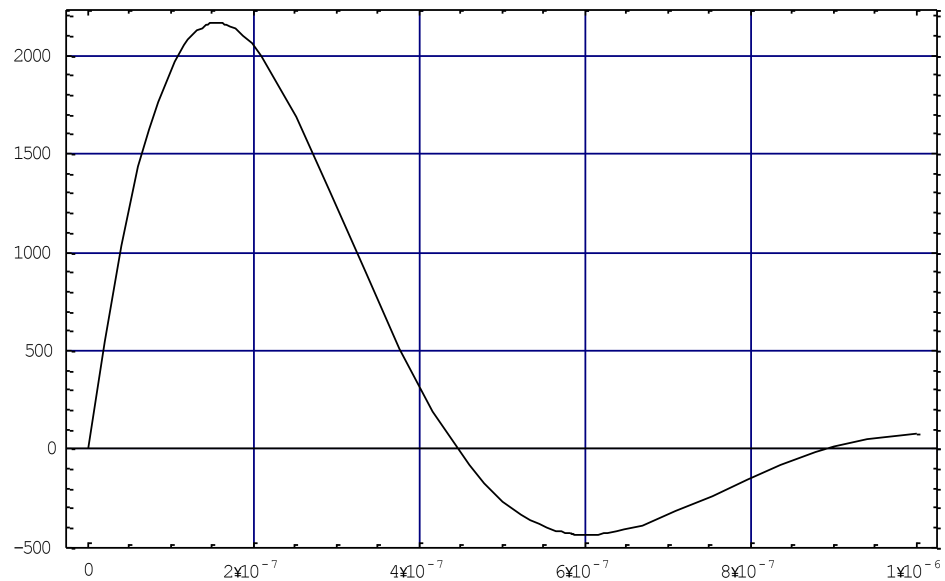




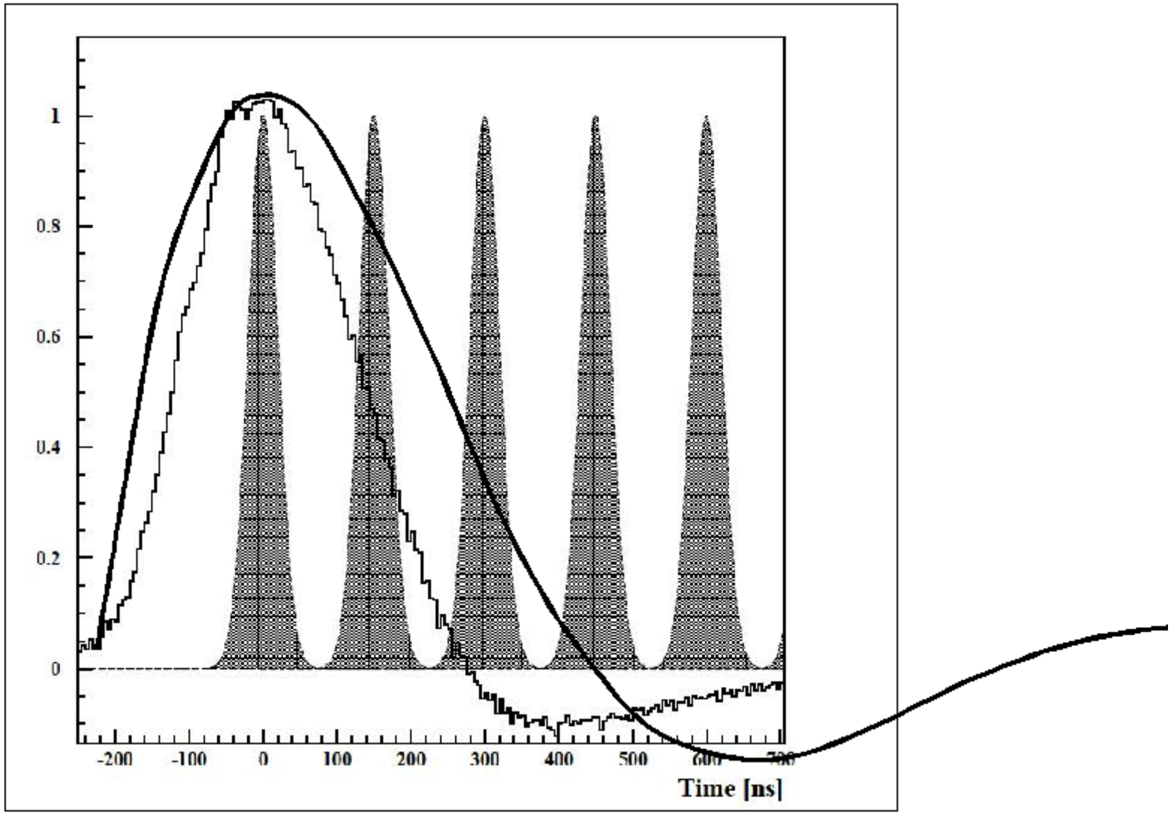
Matched line ($Z_0 = Z_L$)

$\tau = 2L/c \sqrt{(\mu_r \varepsilon_r)}$

Computed pulse shape



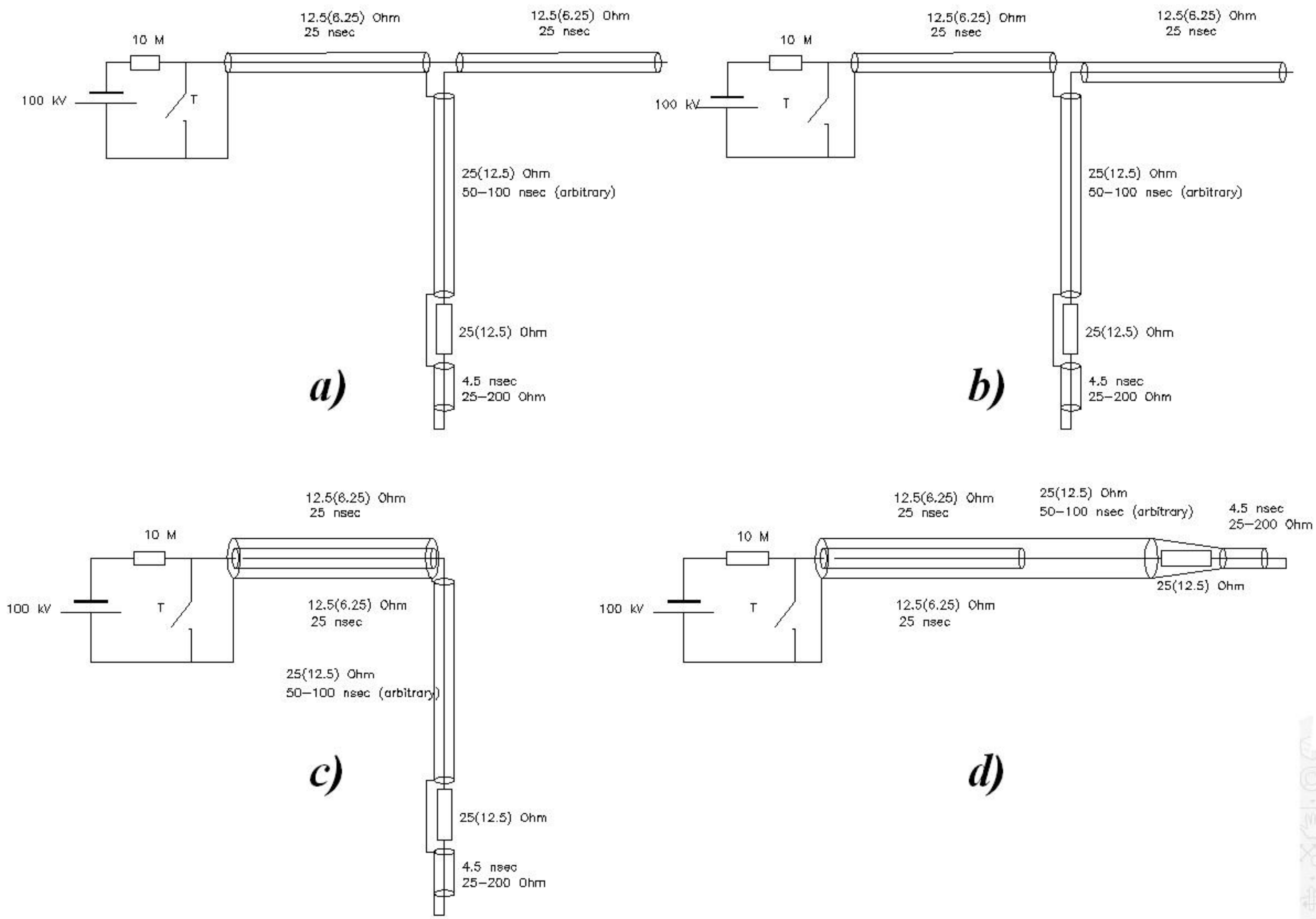
Meanwhile the current shape from previous figures, if embedded in Fig. 51 from [1] (and all other publications), become as the following



The Fig.51 from [1] with superimposed pulse shape obtained from Mathematica©.

The source of this discrepancy is under investigation.

For modeling with PSPICE (Cadence)



a) Original Blumlein scheme;

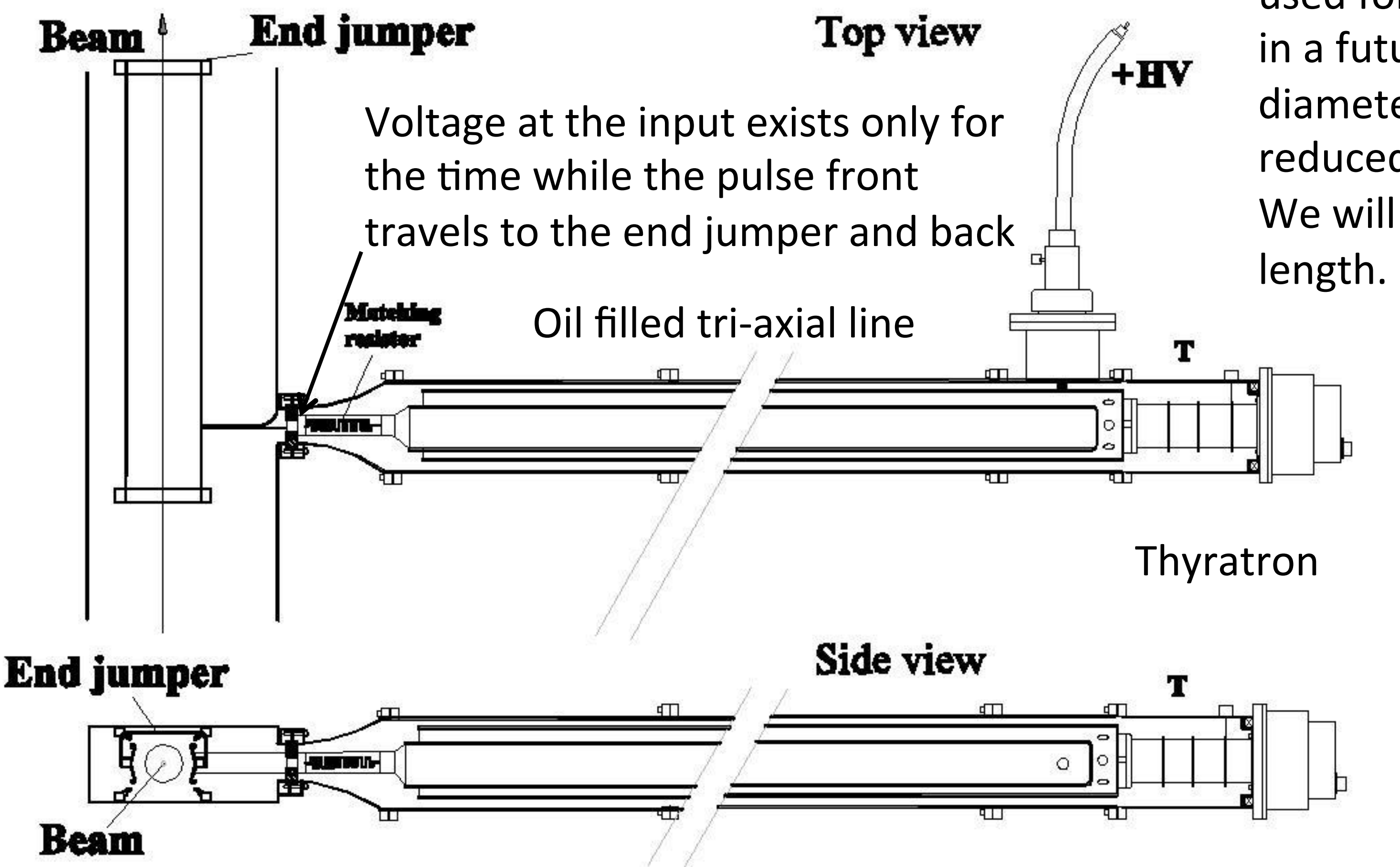
b) In a second coaxial the conductors are switched, so the potential of inner left coaxial is the same as the potential of outer right coaxial;

c) Right coaxial inserted into the left one. For this purposes its radiuses increased accordingly.

d) Final scheme.

Scheme under development

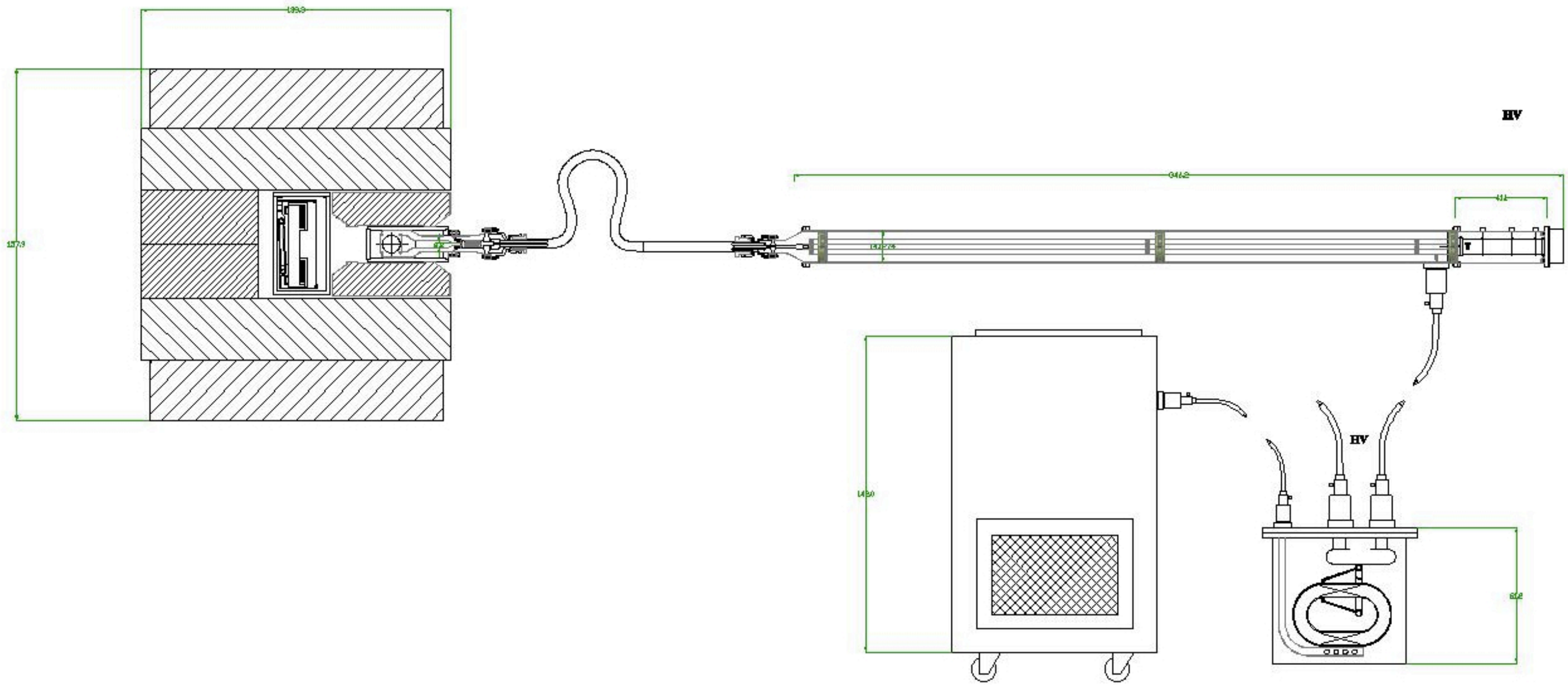
The tubing of the same outer diameter will be used for prototyping; in a future the outer diameter can be reduced ~2 times.
We will add~4 m to the length.



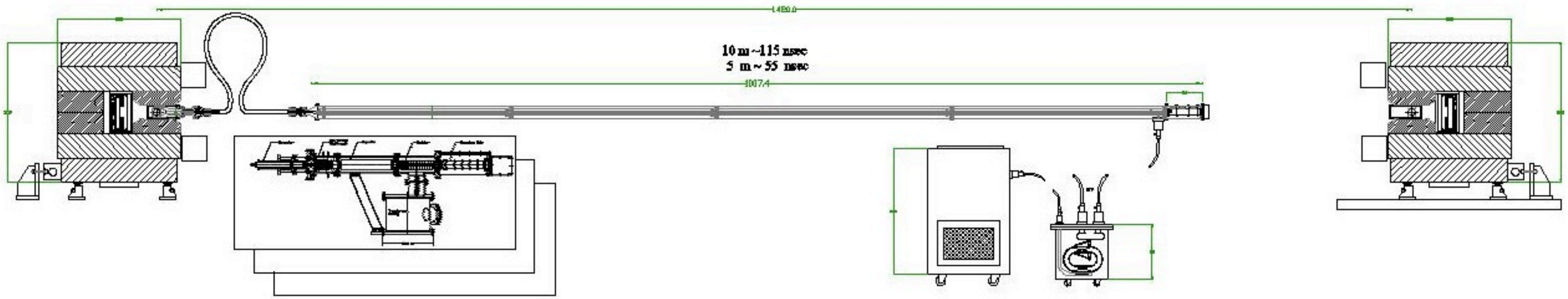
Voltage at the input exists only for the time while the pulse front travels to the end jumper and back

Oil filled tri-axial line

Thyratron

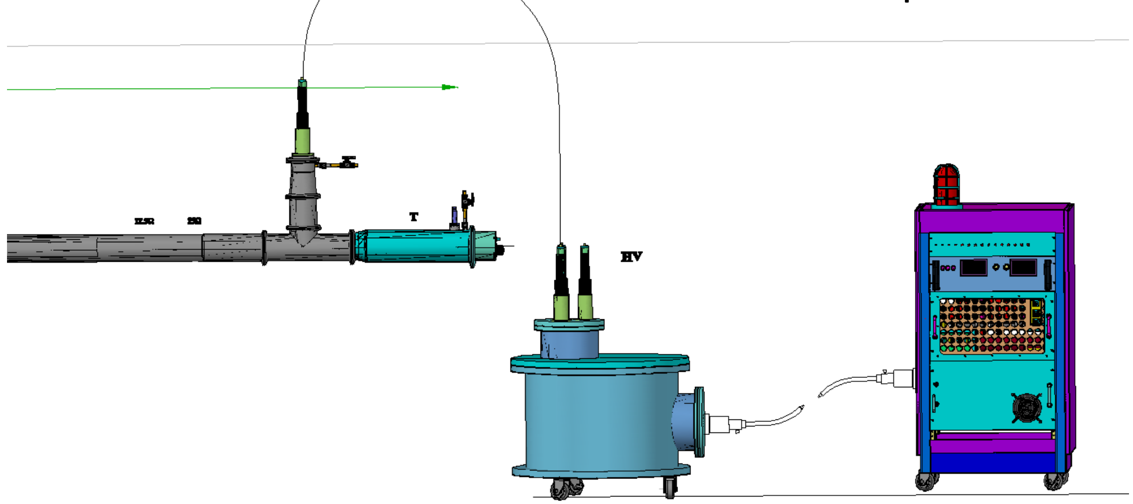

HV
HV

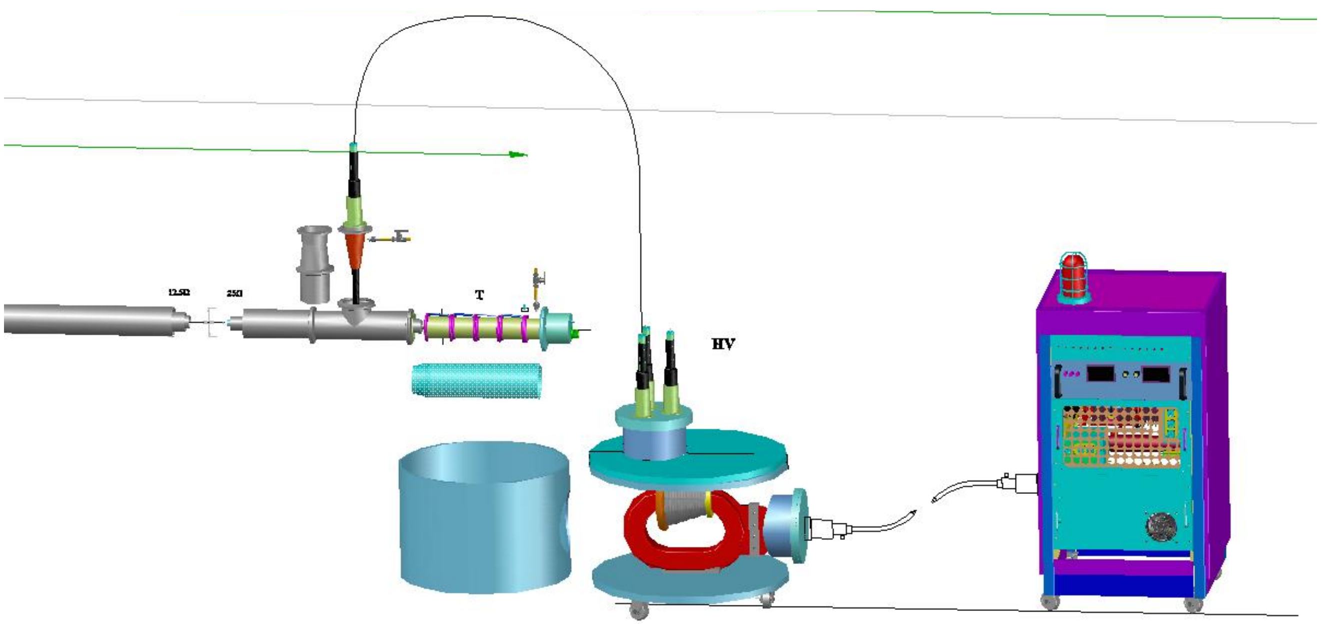
L=10m => τ = 115 ms



Rigid coaxial delay line

Thyratron end station with transformer tank and HV pulser

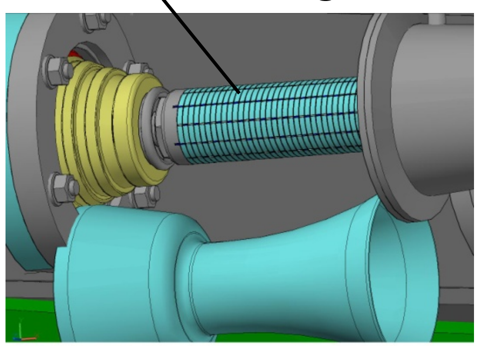




For prototyping we are planning to use existing thyratron housing and tubing system

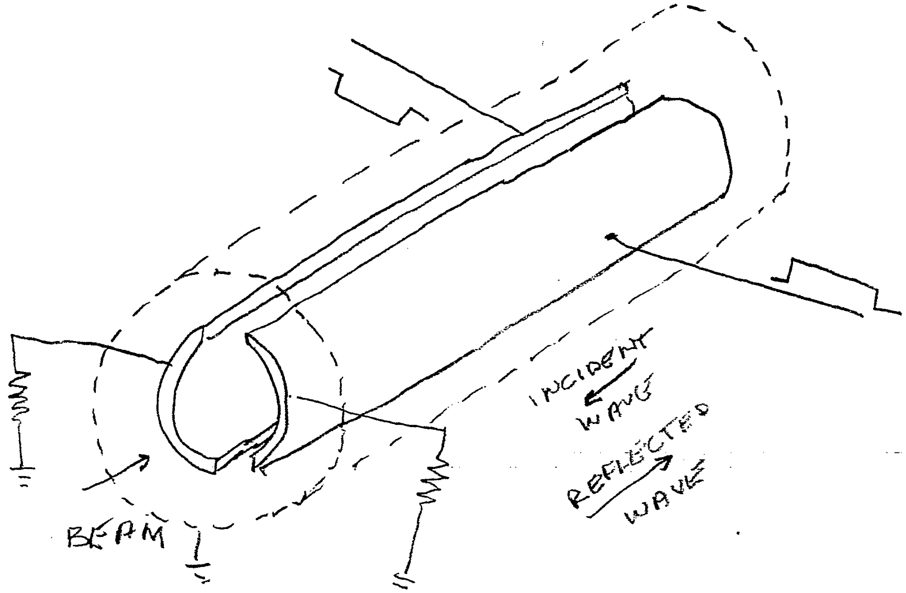
Generator for 120ns pulse line in scale with g-2 ring

Matching resistor

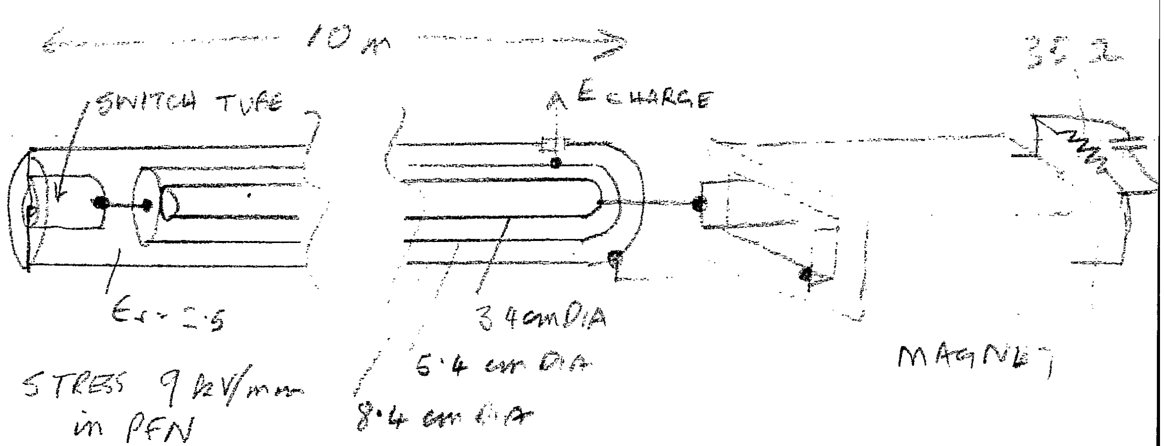


Blumlein application at BNL with similar to parameters to g-2

Pulsed Power Supplies for RHIC
E. Forsyth, M. Meth, W. Zhang
October 1991



A



B

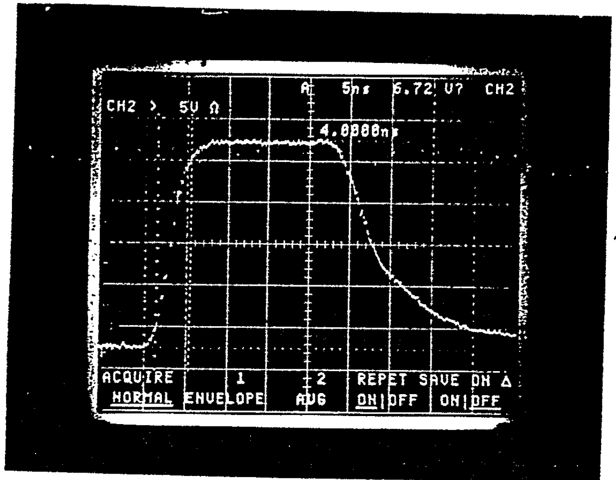


Fig. 12a. THE OUTPUT PULSE WAVEFORM WITH C_2 = 27 pF, C_3 = 38pF, R_3 = 33 Ω.

RHIC kicker pulse

RHIC kicker

5ns/div

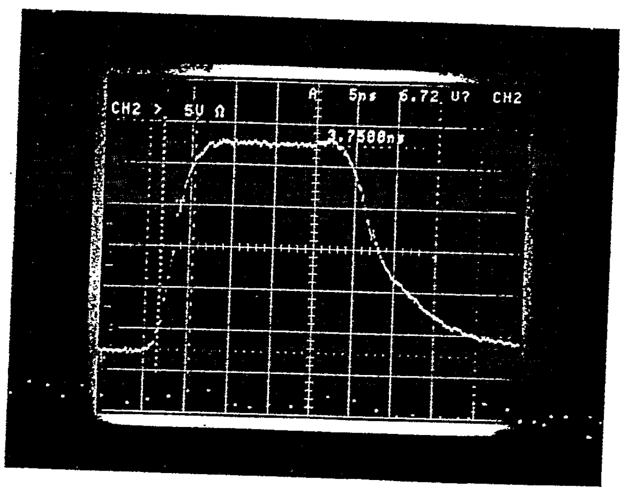


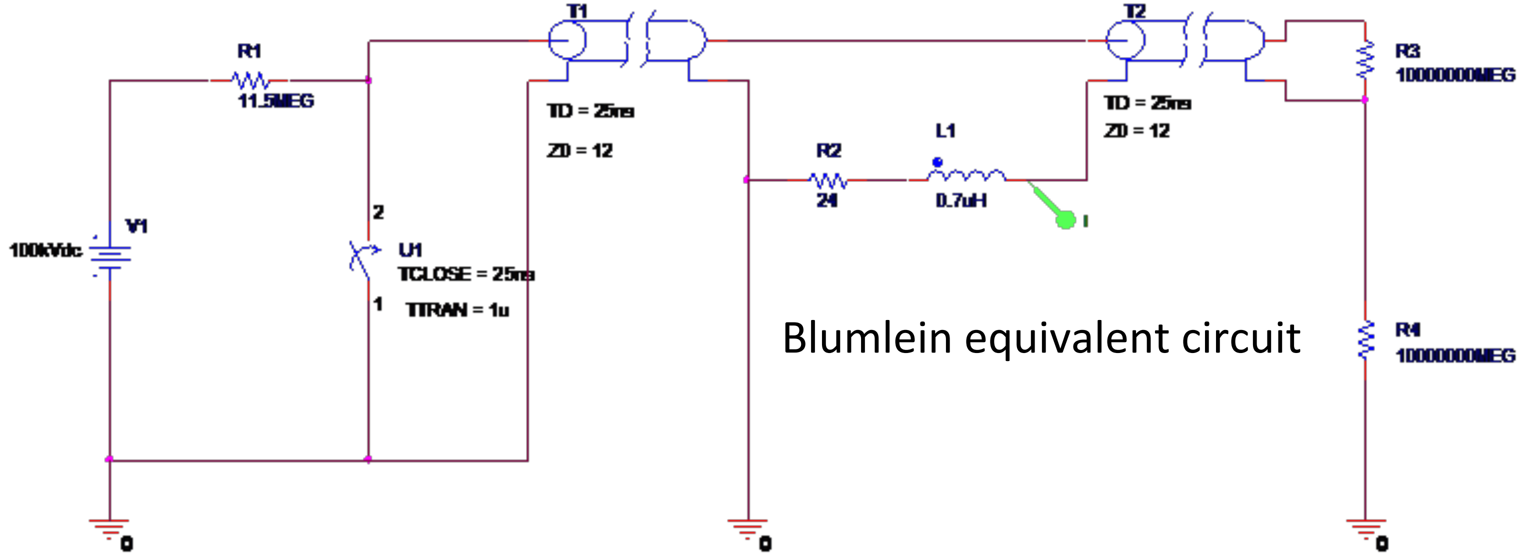
Fig. 12b. THE OUTPUT PULSE WAVEFORM WITH C_2 = 32 pF, C_3 = 38 pF, R_3 = 33 Ω.

Kicker pulse with blumlein PFN

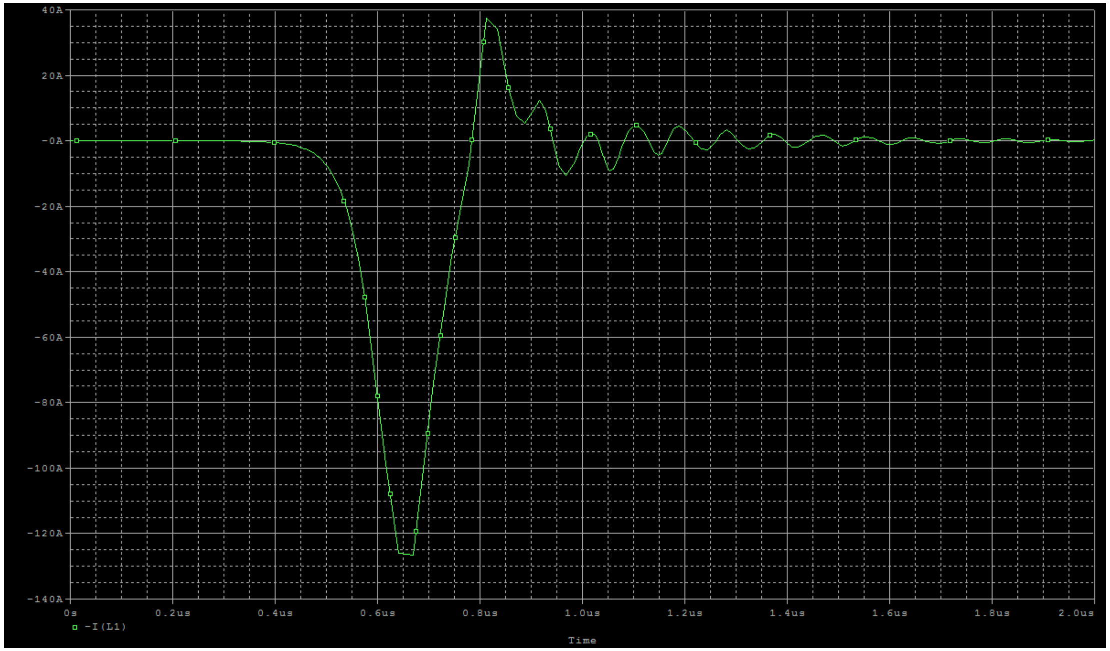
Matching components

Few triaxial Blumlein generators at RHIC inflector

Pulser Modeling

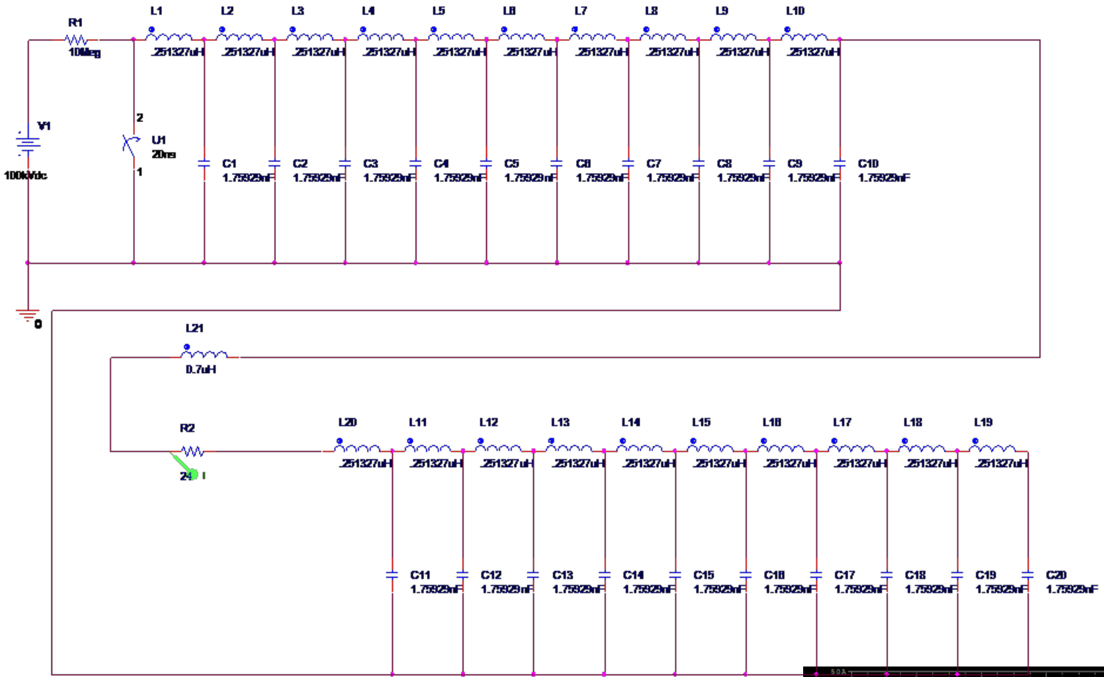


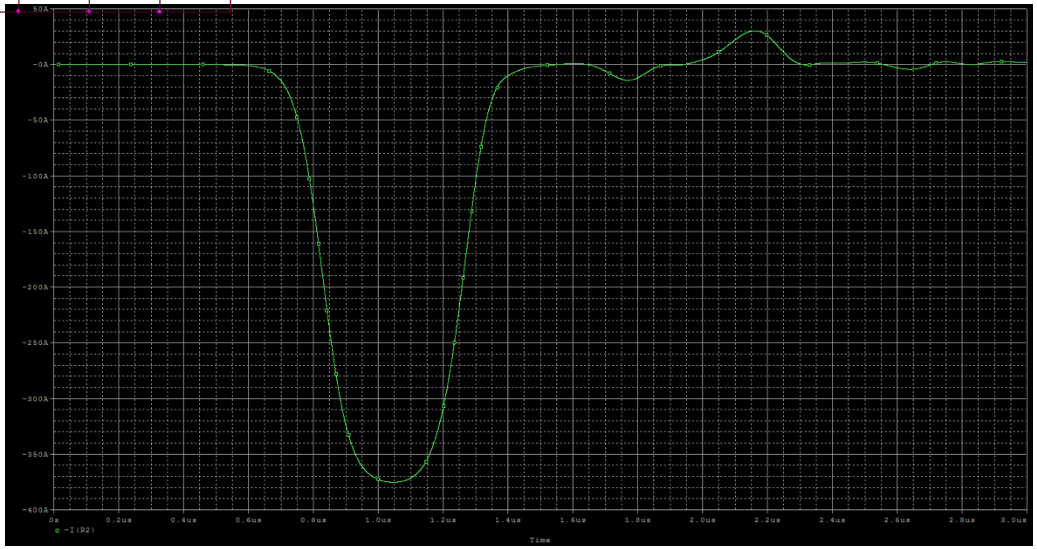
Blumlein equivalent circuit



preliminary

Lumped line blumlein equivalent





Preliminary

Modeling plan

- Continue to develop facility with SPICE

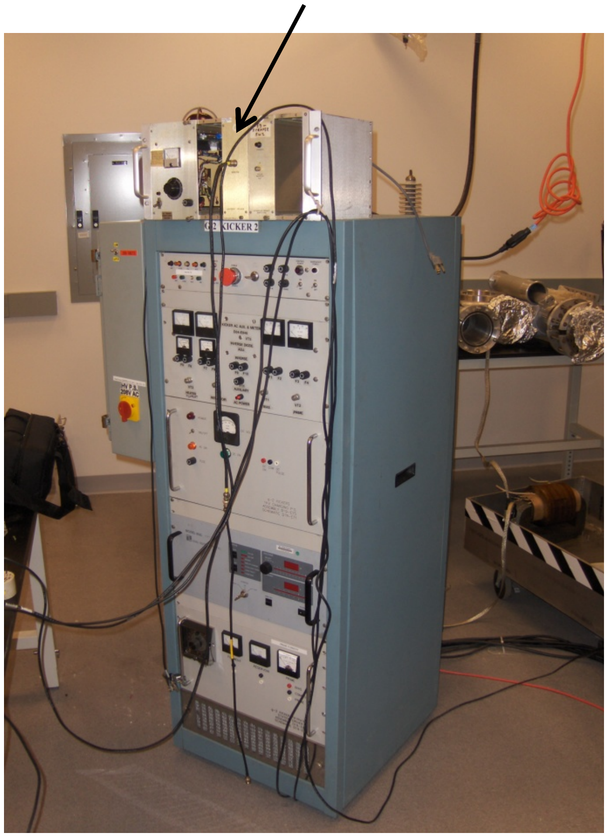
- J. Bennett is learning CST Micro-wave studio to model
  - blumlein coax
  - magnet stripline
  - eddy currents in vacuum chamber
  - time dependence of kick field

Status of prototype test

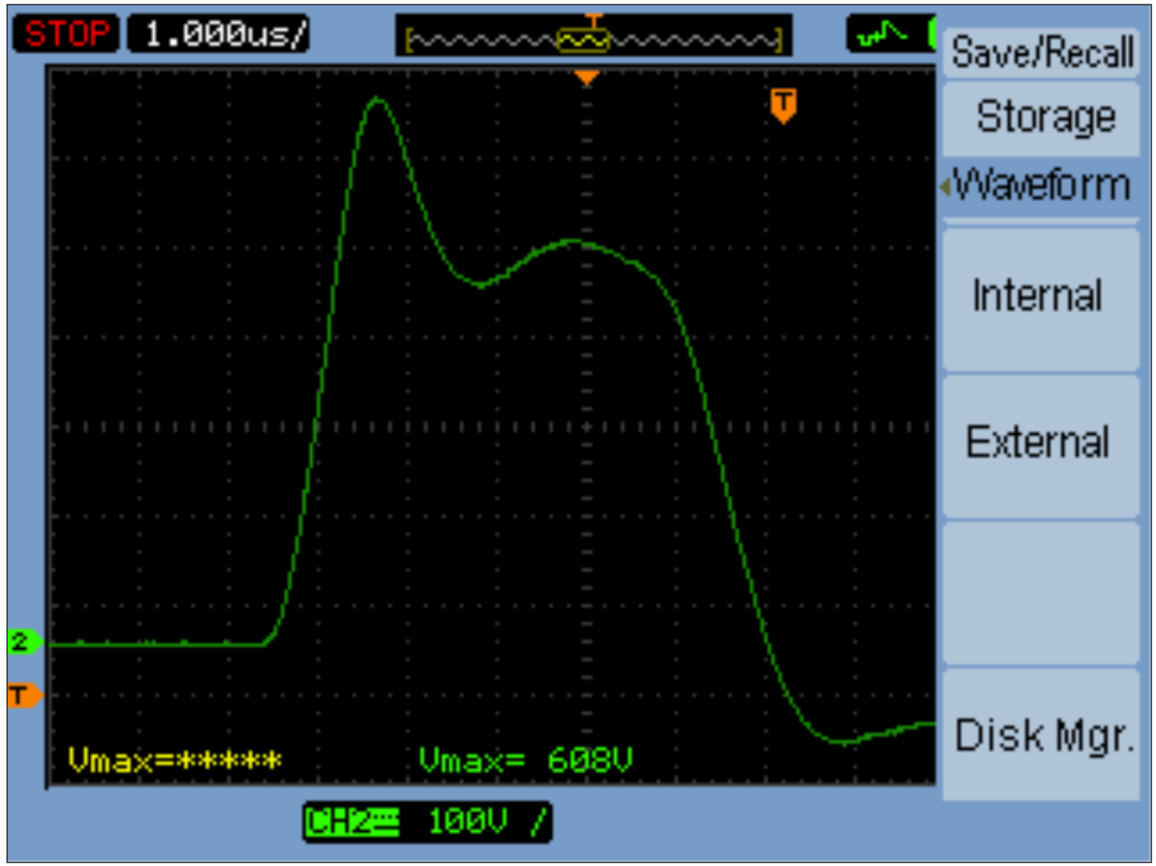
Restoring the E-821 prototype pulser and kicker
Repaired and replaced electronic compnents
- Thyratron electronics
    - Reservoir
    - Heater
    - Trigger pulser (second grid)
    - (Meanwhile, primary grid supply has failed)
- HV power supply tested
- HV transformer tested

Thyratron grid pulser; this pulse goes to the second grid

Thyratron grid pulser



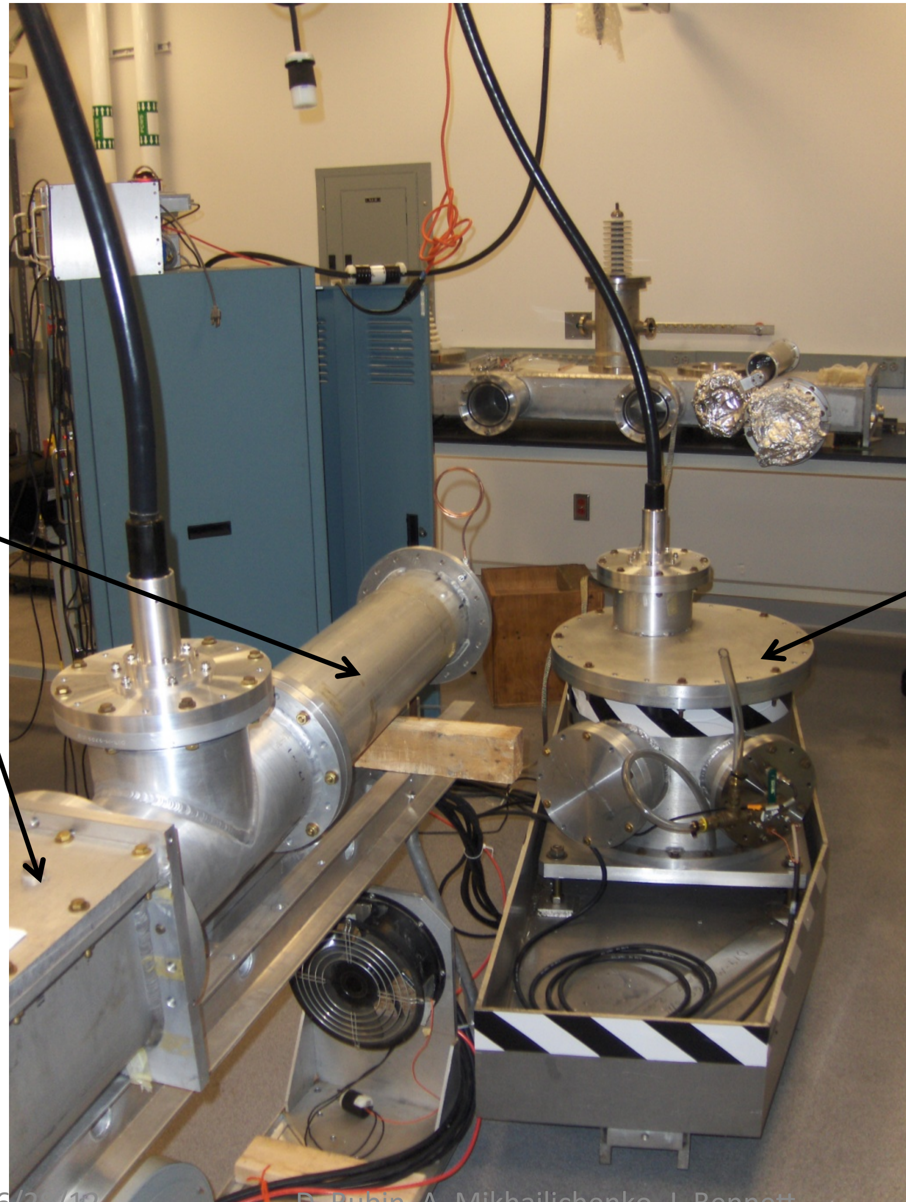
Unloaded



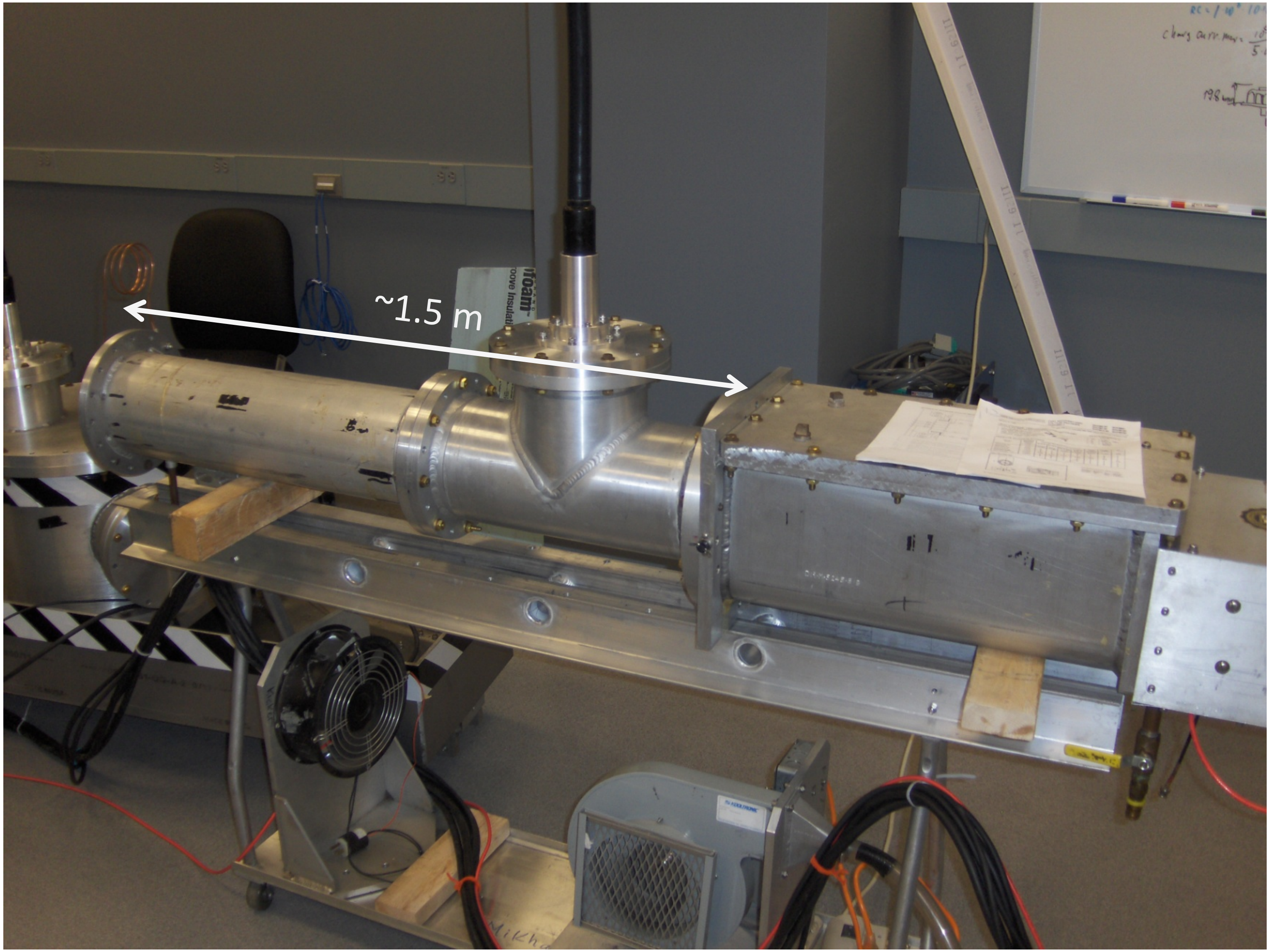
For triggering CX1699 the amplitude on grid 2 required : 500-2kV, 0.5 µS

Thyratron/capacitor

HV transformer tank

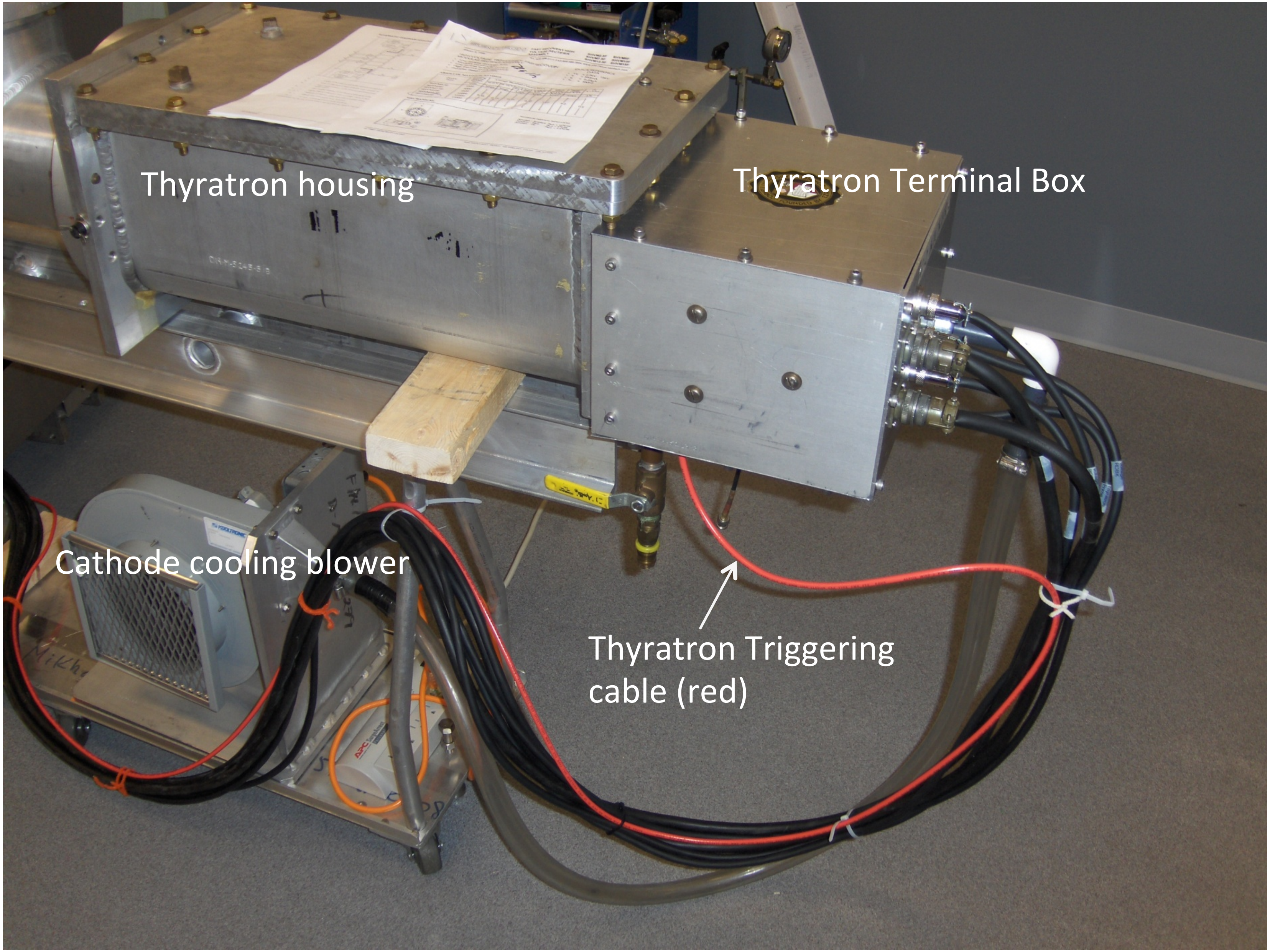


For the Blumlein generator prototyping this 1.5 m-long section will be extended by 4 meters

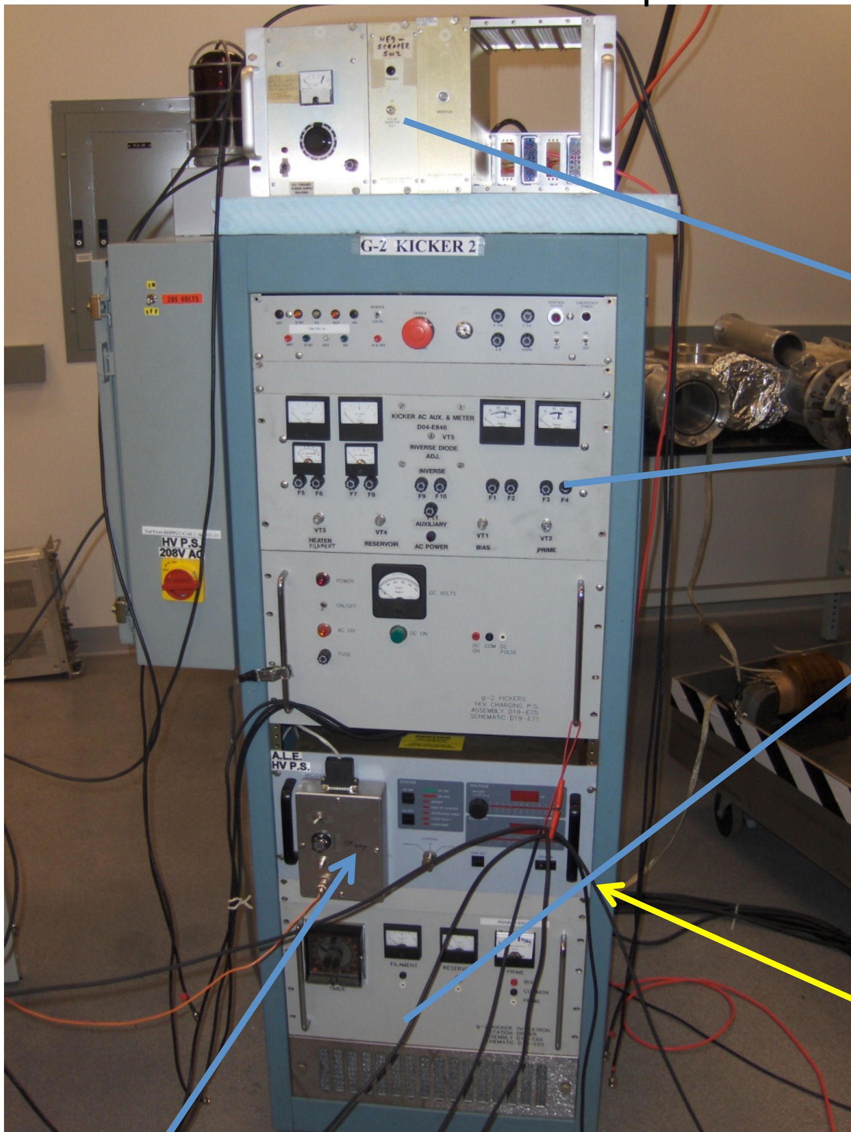


This will allow having 50ns flat top pulse

Fits in the room


Thyratron housing
Thyratron Terminal Box
Cathode cooling blower
Thyratron Triggering
cable (red)

We recommend to purchase the thyratron feeding unit



NORTH STAR HIGH VOLTAGE

North Star High Voltage
12604 N New Reflection Dr
Marana, AZ, 85658
520 260 8687
206 219 4205 FAX
sales@highvoltageprobes.com
www.highvoltageprobes.com

Thyratron Chassis with Driver, Heater and Reservoir Power

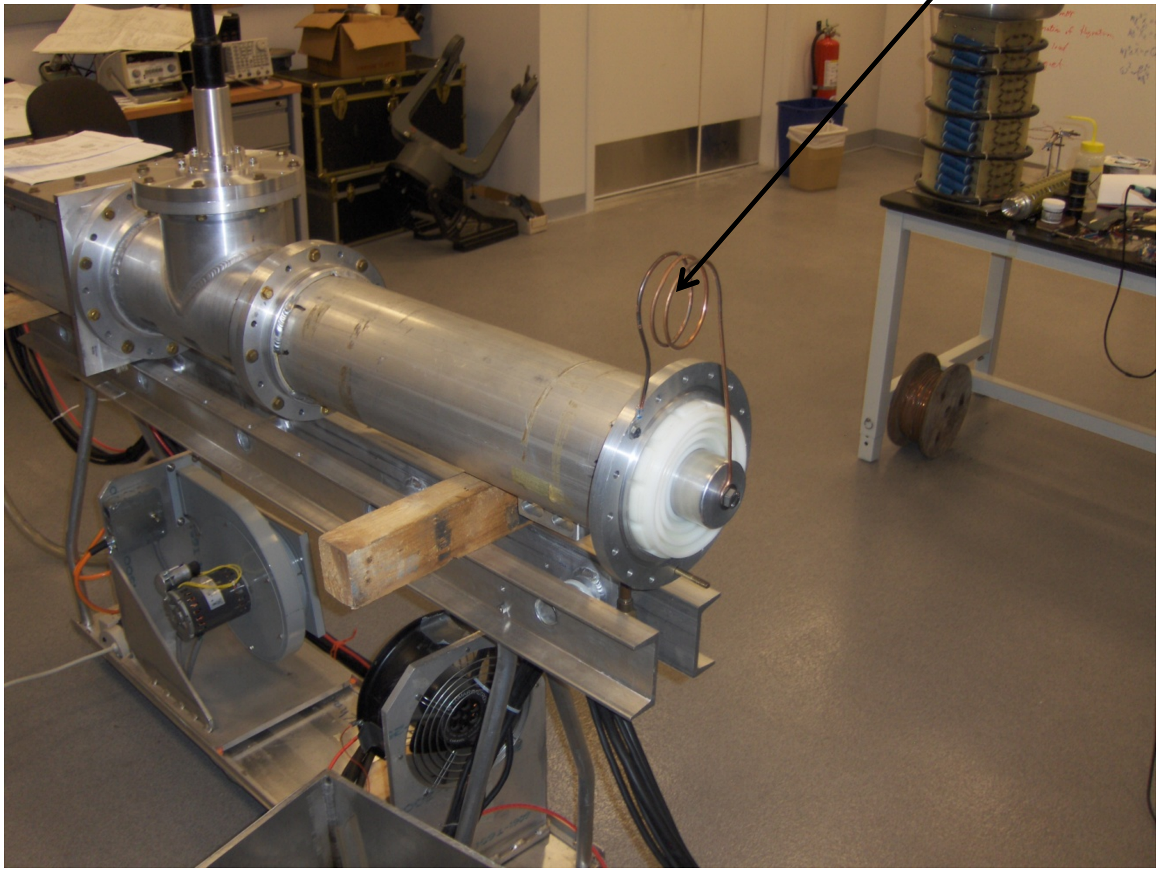
This block **replaces** the thyratron triggering pulser, the PS for the heater, reservoir, prime, bias.

The cost is $5500/one
$15000/set of three

For the reference: the cost of this HV PS is 12.5k$

New HV regulation block

Inductance ~1μH



Without oil this device can operate at ~ 30KV

Other view

High voltage operation > 30kV (target is 100kV) requires that HV transformer, resistor, thyratron be bathed in oil – requires flanges to seal.

We had hoped to test without oil, but thyratron does not fire at 30kV
Thyratron problem
or 30kV insufficient to initiate breakdown in tube

Next step is to fill with oil and test with dummy load

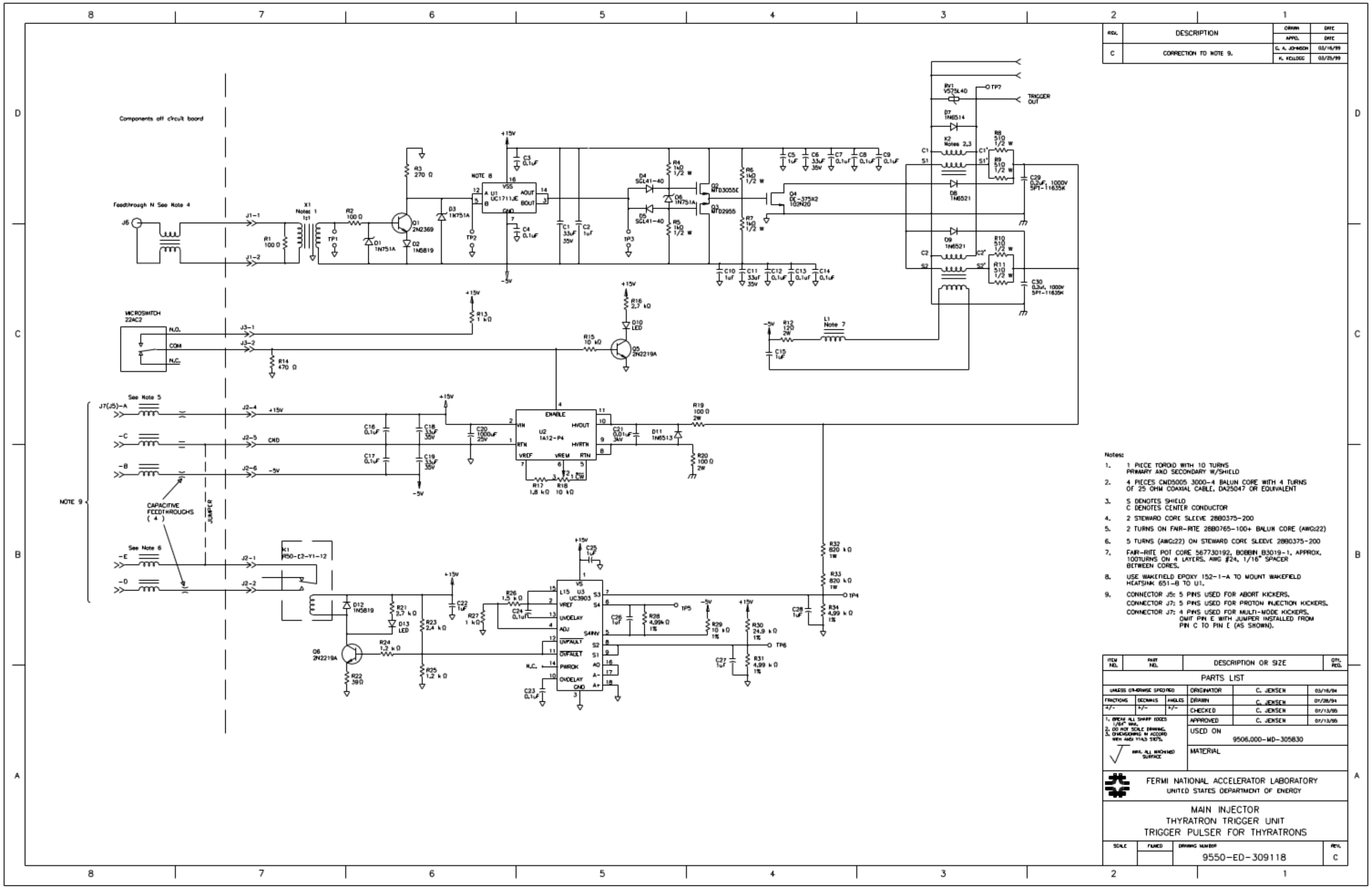
Meanwhile we are building a prototype blumlein

Three sections of the Blumlein generator in a machine shop.

Summary

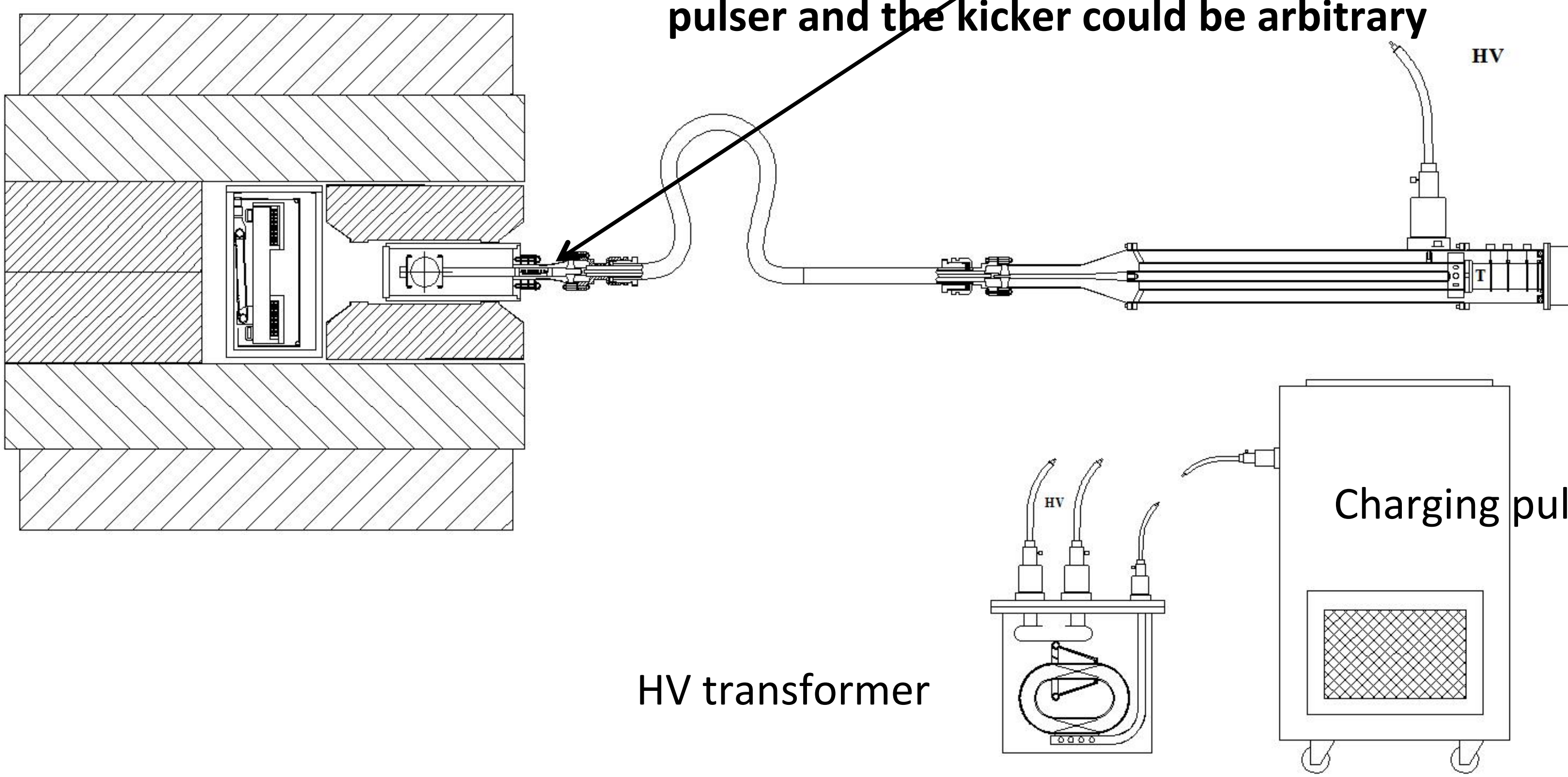
1. Design for kicker plates with uniform field
2. Design for PFN (bumlein) for 50 ns pulse
3. Developing models of pulser, kicker, including interconnects and vacuum chamber for simulation of time dependence of B-field, eddy currents etc. using SPICE and MicroWave Studio
4. Very nearly testing E-821 pulser with load
5. Fabricating prototype blumlein
6. Plan to test blumlein, and tune, guided by simulation

Scheme (and hardware) received from Chris Jensen



This scheme is restored finally and is ready to use.
Generates ~860 V unloaded, ~800ns duration

With matched resistor the distance between HV pulser and the kicker could be arbitrary



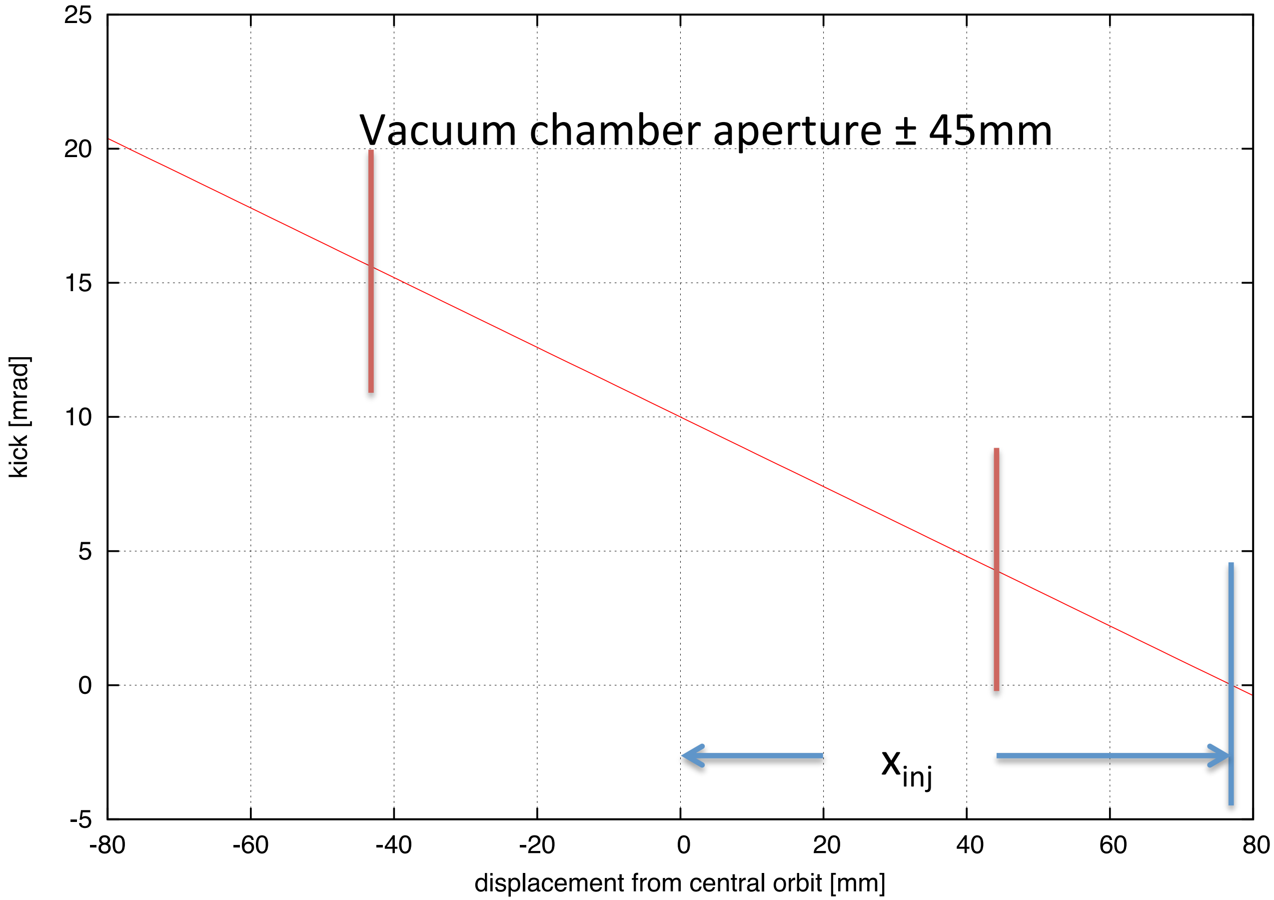
Blumlein pulser:

Provides higher current;

Flat top pulse without tails;

Optimized electrodes will provide higher Field/current ratio

THEORETICALLY JUST A SINGLE KICKER CAN PROVIDE ENTIRE KICK



Energy dependence

If the kicker field depends on displacement from central orbit according to kick [mrad] ≈ $10(1-x/x_{inj})$ then all energies kicked onto corresponding closed orbit

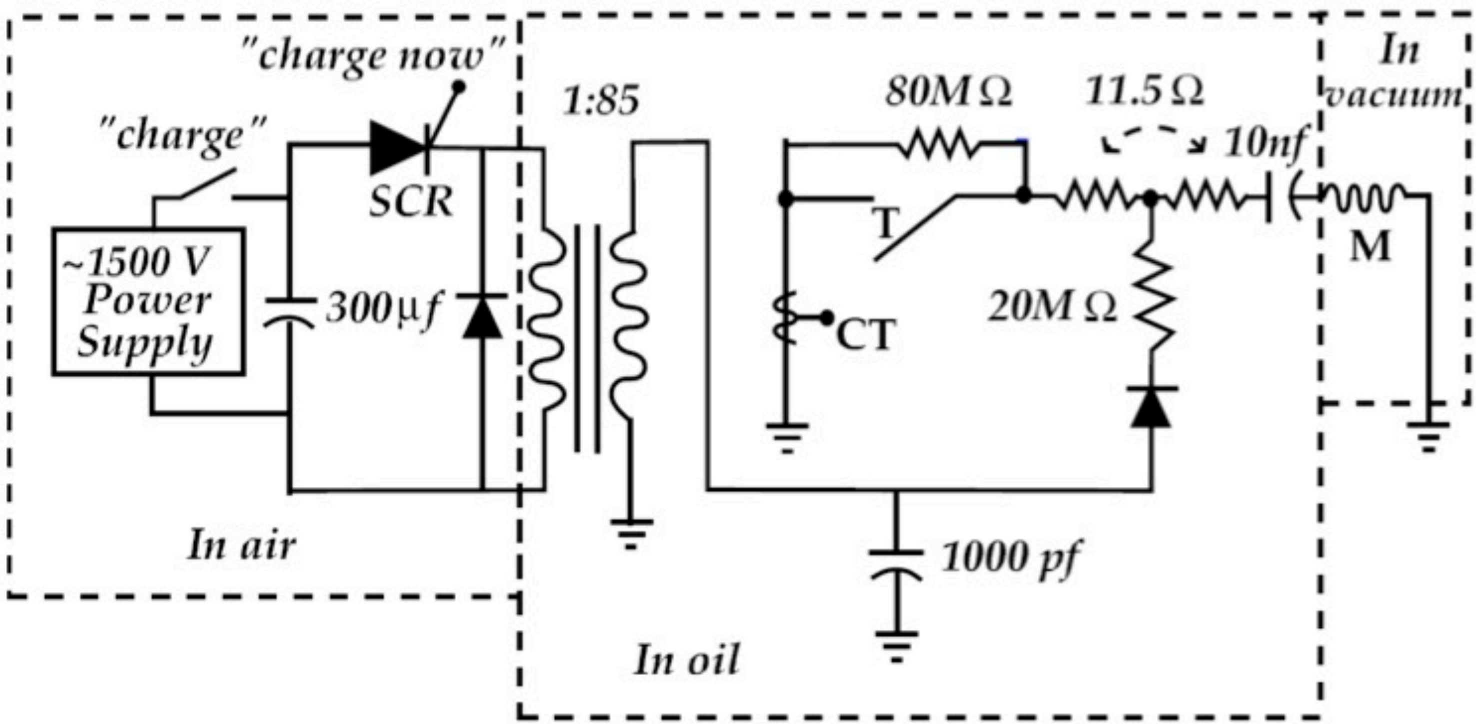
Dependence on angular distribution of injected muons

$$\begin{aligned} x(s) &= x_{\rm inf}\cos\phi_x + \beta x'_{\rm inf}\sin\phi_x \\ x'(s) &= -\frac{x_{\rm inf}}{\beta}\sin\phi_x + x'_{\rm inf}\cos\phi_x \end{aligned}$$

Then at Φ = π/2

$$\begin{aligned} x(\frac{\pi}{2}) &= \beta x'_{\rm inf} \\ x'(\frac{\pi}{2}) &= -\frac{x_{\rm inf}}{\beta} \end{aligned}$$

There is no kick that puts the muon onto the central orbit
The best we can do is to minimize the invariant amplitude



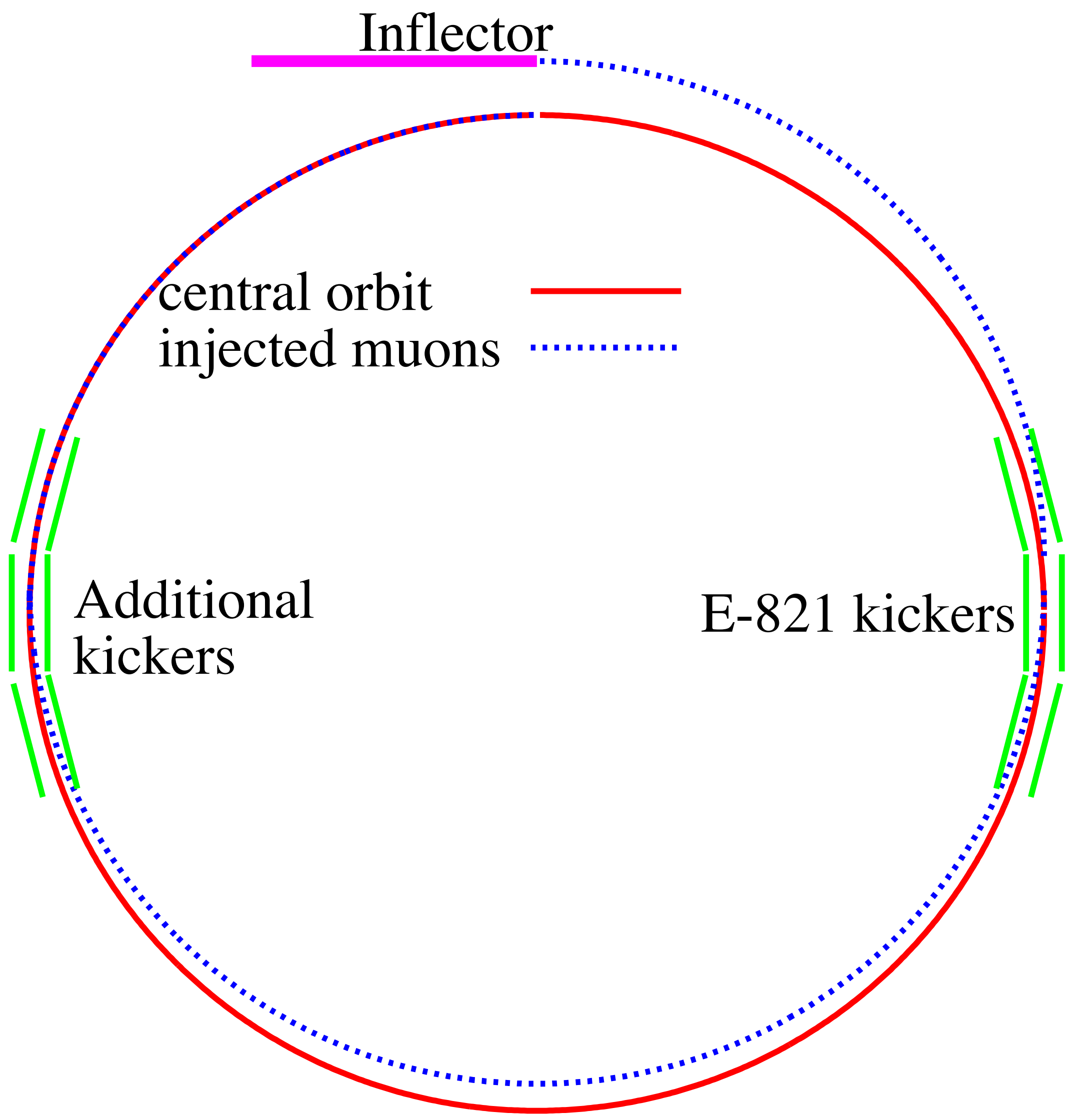
E821 – Pulser schematic

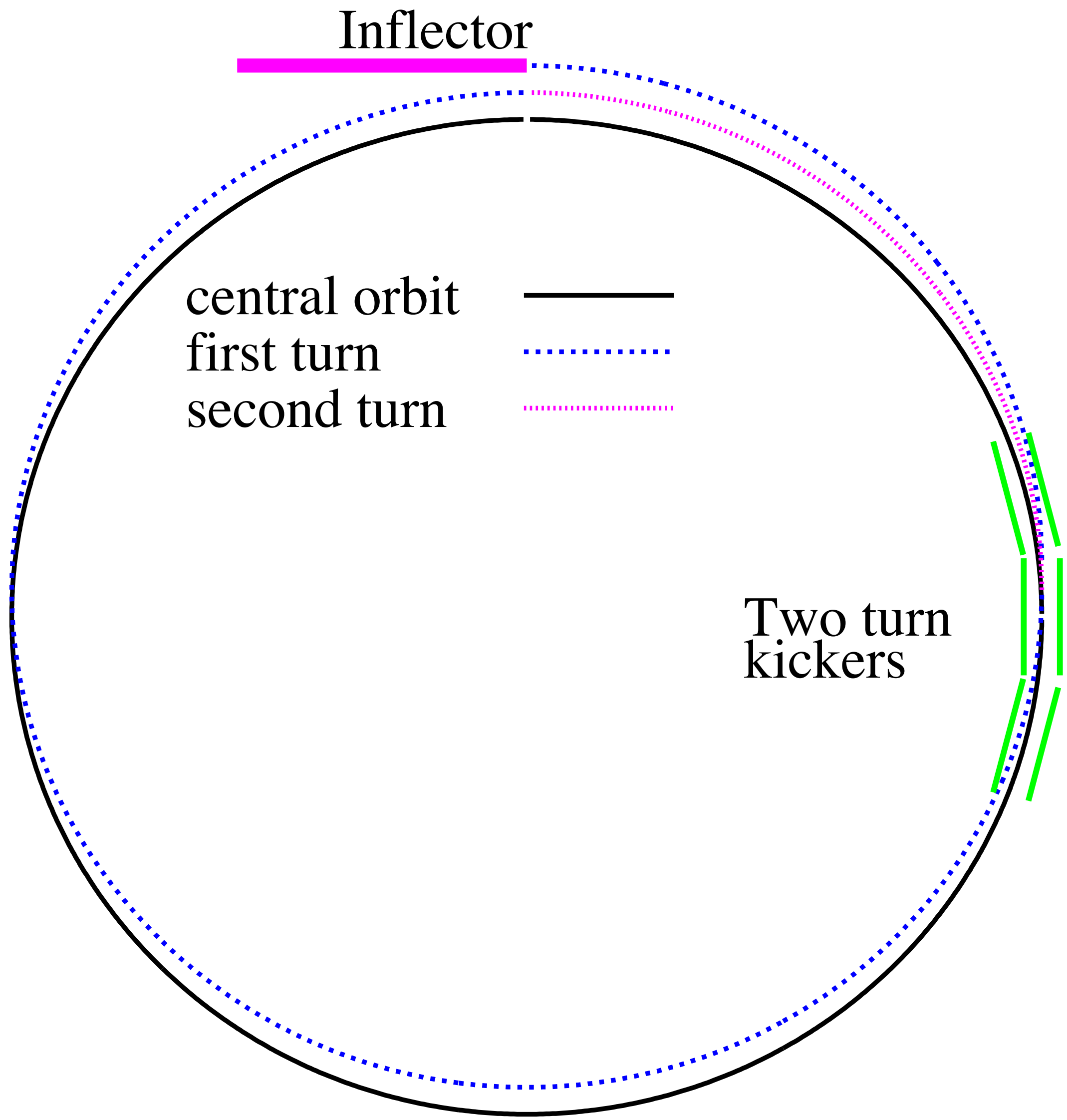
Thyratron feeding section is running

SCOPE OF WORK

At a period of 2012, Cornell plans to provide:

√ Analyses of injection efficiency;
√ Optimization of injection;
√ Analyses of existing kicker system performance with 3D codes;
√ Reinstallation the E-821 hardware at Cornell and test; (accommodation in HV lab)
● Fast field measurement equipment in existing model;
√ Suggest the primary modification of the pulse generator and the kicker;
√ Analyses of a new generator;
● **Complete drawings** of the new generator and kicker;
● Assembling a full scale prototype of a new pulser (Blumline) and the kicker;
● Test the prototype and the kicker together;
● Design drawings of a Blumlein pulsed system able generation of bi-polar pulses without mechanical switching;


Inflector
central orbit
injected muons
Additional
kickers
E-821 kickers


Inflector
central orbit
first turn
second turn
Two turn kickers